Boyle.

Manganese Steel Castings.

MANGANESE STEEL CASTINGS

BY

CLARENCE BOYLE, JR.

B. S. UNIVERSITY OF ILLINOIS, 1910

THESIS

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I HEREBY RECOMMEND THAT THE THESIS PREPARED BY

Clarence Boyle, Jr.

ENTITLED Manganese Steel Castings.

BE ACCEPTED AS FULFILLING THIS PART ON THE REQUIREMENTS FOR THE PROFESSIONAL DEGREE OF Mechanical Engineer.

C. R. Richards

Head of Department of Mech. Engineering

Recommendation concurred in:

C. R. Richards
Edward C. Schmidt
G. A. Goodenough

Committee

Dedication

This work is dedicated to

SIR ROBERT A. HADFIELD, F. R. S.

the discoverer of manganese steel

to whom the writer is indebted

for courtesies rendered.

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MANGANESE STEEL CASTINGS

I

Introductory.

The purpose of this work is to set forth in a clear and easily understood manner the important characteristics of that alloy of steel known as manganese steel and to describe at some length the various applications of manganese steel castings.

It is interesting to note that manganese steel was the first iron alloy to be fully described to the world and this no longer agao than 1888. In view of the universal uses of iron and steel alloys at the present time and the enormous advances which have been made in metallurgical and metallographical knowledge, the discovery and publication of the very peculiar characteristics of this material may well be considered of the utmost importance.

The early ideas regarding the amount of manganese in steel were confined entirely to small quantities, say 2% and less. Practically all steels contain some manganese which is usually added in the form of ferro-manganese to act as a cleanser by combining with the impurities and passing off with the slag. In other words, referring particularly to the Bessemer process, ferrous oxide is soluble in the bath and to avoid yielding a metal saturated with the oxide, a manganeseous iron is used. Manga-

nese then reduces the oxide which has not already been reduced by the presence of silicon, carbon, or phosphorus and prevents a saturation of the metal by ferrous oxide.

It was long known that the presence of 1.5 % manganese in steel resulted in making such steel unusually hard and brittle. It was noted that an increase in the percentage of manganese increased this brittleness to a marked extent. Therefore, any great quantity of manganese in steel was looked upon as being most undesirable.

Such was the state of affairs when on the seventh day of the ninth month, 1882 in Sheffield, England, Robert A. Hadfield began some experiments on the addition of larger percentages of manganese in steel which resulted in the discovery of that most import alloy now known as manganese steel. A plate giving a reproduction of the notes entered immediately after these first experiments is given on page 49 of the Appendix.

For a year or two research work was carried on by the present Sir Robert A. Hadfield, F. R. S. without any public mention being made of "this fascinating material with all its peculiar qualities-hard when it should be tough, tough when it should be brittle, brittle when it should be tough, non-magnetic when it should be magnetic seeing there is no less than 88% to 90% of iron in its composition, elongating no less than 50% on 8", and possessing a tenacity of 60 to 70 tons per square inch", to quote from a

letter by Sir Hadfield to the writer.

After the invention had been patented the essential facts were made public for the first time in the February 8th, 1884 edition of "The Engineer" in an article entitled "Hadfield's Patent Manganese Steel." A photostat of this reference is included on page 50 of the Appendix. The late Joseph D. Weeks of Pittsburgh was the first man in America to take an active interest in manganese steel. He was then Editor of the "Iron Trade Review" and he read the first paper in this or any other country on manganese steel before the American Institute of Mining Engineers in 1884. This he followed with another paper read before the same body two years later.

In 1888 the inventor or discoverer of this remarkable alloy, Sir Robert A. Hadfield, read two most exhaustive papers on this subject before the Institution of Civil Engineers. A list of later papers pertaining to this subject by the same author is given in the Appendix. The importance of this invention to the scientific world in general, and the far reaching results of research and investigation subsequent there-to, is indicated by the list of awards and honors to Sir Hadfield, and the remarks by various scientists on his research work in connection with manganese steel all of which records are included in the Appendix.

For ten years after the first manganese steel castings were made in 1882, the entire output was confined to the material

produced by Messrs. Hadfield Ltd. of Sheffield, England, one of the principal applications being for dredge pins used in ladder dredges. The introduction of manganese steel into America is due largely to the early interest taken in the subject by Professor Henry M. Howe of Columbia University who had several conferences with Sir Hadfield during one of his visits to Europe while preparing notes for his important work"the Metallurgy of Steel" published in 1890. It was he who introduced the late W. J. Taylor then President of the Taylor Iron & Steel Co., High Bridge, N. J., to Sir Hadfield with the result that this company secured the exclusive rights to manufacture manganese steel in America under the Hadfield patents and system.

Thus the first heat of manganese steel was successfully made in this country in November, 1892 at the High Bridge, N. J. plant of the Taylor Iron & Steel Co. (now the Taylor-Wharton Iron & Steel Co.) Since that time the production has increased by leaps and bounds until the annual capacity of manganese steel foundries in this country alone is now in excess of 60,000 tons. The writer is informed by Sir Hadfield under date of January 21, 1916 "that although other products are made by Messrs. Hadfields Ltd. of Sheffield, they are still the largest producers in the world of this important material."

We will now consider some of the peculiar qualities of manganese steel which have served both to extend and to limit its uses in various applications.

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II

Physical Properties

The product known commercially as manganese steel has a chemical composition of about the following range

	Per Cent	Average Per Cent
Manganese	11.00 to 13.50	12.50
Carbon	1.00 to 1.30	1.25
Silicon	.25 to .40	.30
Phosphorus	.05 to .11	.08
Sulphur	.01 to .02	.02
Iron	84.00 to 87.00	85.85
		100.00

A graphical explanation of the above limits in the percentage of manganese is given on the following page, showing the influence of the proportion of manganese on the tensile strength and on the ductibility of manganese steel both when slowly cooled and when suddenly cooled by quenching in water. This chart which is compiled from the results of tests by Professor Henry M. Howe also shows the remarkable effect of sudden cooling and emphasizes the necessity for proper heat treatment.

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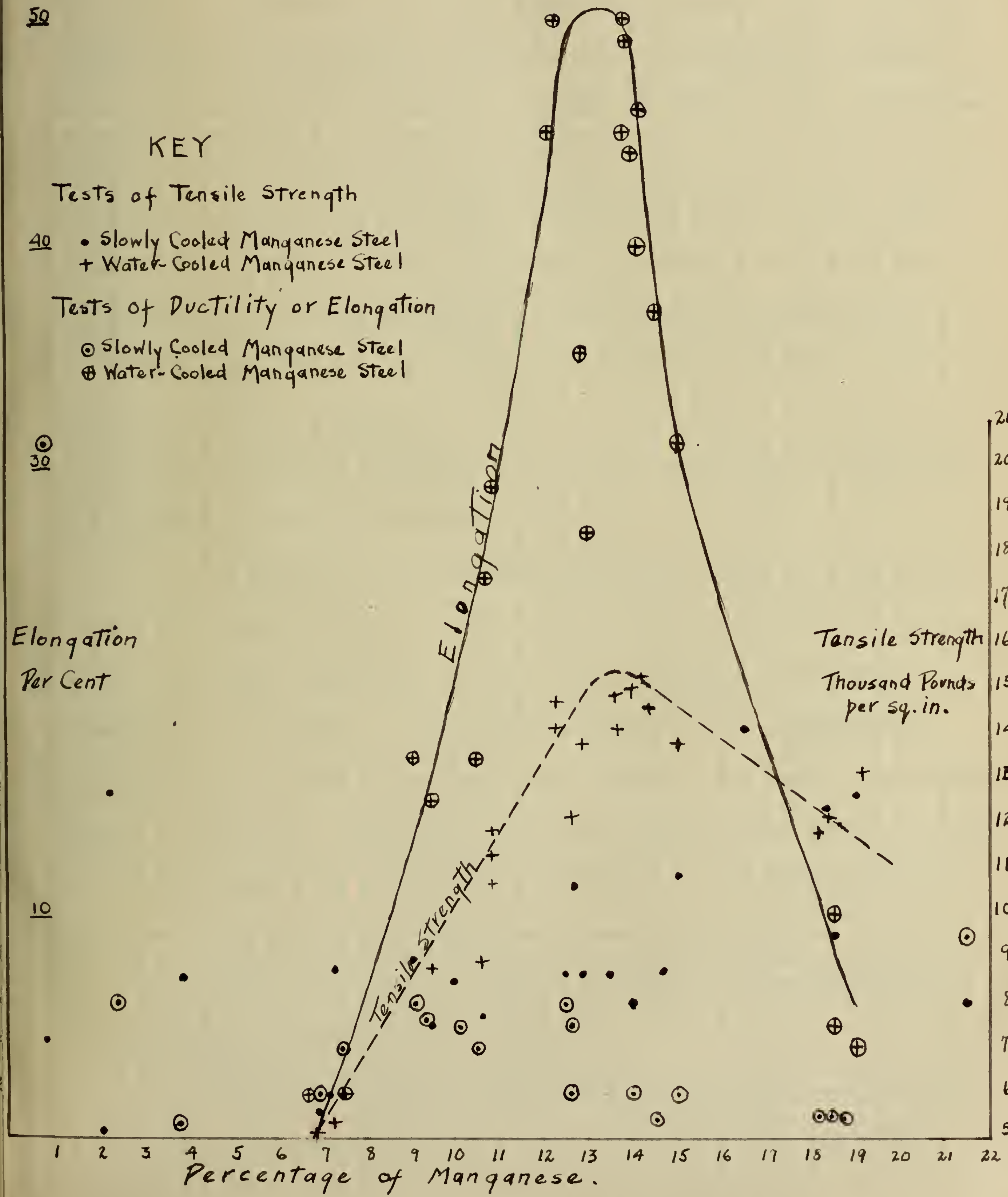
Plate A - Influence of the Proportion of Manganese on the Tensile Strength and Ductility of Manganese Steel.



As originally cast, manganese steel is extremely brittle and could be pulverized under the blows of a hammer. A microscopic examination of such material shows that it is composed principally of a solution of iron, manganese, and the carbides of iron and manganese, the above being known as Austenite , together with the carbides of iron and manganese which remain undissolved known as free cementite. The presence of this free cementite which is very hard and brittle causes the entire specimen to have similar characteristics. If it were impossible to eliminate this cementite, manganese steel would be of little commercial value but by heating to a proper temperature and suddenly quenching in water the cementite is dissolved and a uniform austenitic structure results.

The great value of manganese steel cannot be attributed to any one physical property but rather to the combination of such properties which taken together are truly remarkable although in themselves not unusual. Thus manganese steel is not exceedingly hard as compared with other high grade steels. The Brinell hardness number is about 200. Neither is it the toughest known metal although it is very tough as a piece 5/8" x 3/8" can be bent double without fracture. Yet in the combination of these two properties it excels all other metals. It is very hard considering its toughness and unusually tough considering its hardness.

It is difficult to give definite numerical figures for the various physical properties of manganese steel for the reason

that a slight change in chemical composition or as is more likely to happen, a variance in the heat treatment, will greatly affect the results of tests. It should not be assumed from this that manganese steel castings as actually turned out are not uniform, for as a general rule they are more dependable than ordinary steel castings, but it will explain the fact that various authorities differ somewhat as to such properties. A safe average is given by the following figures: Tensile strength 110,000 lbs. per square inch; elastic limit 54,000 lbs. per square inch; elongation on 8", 45%; reduction of area 50%; elongation on 2", 34%, reduction of area 39%.

One of the most peculiar characteristics of manganese steel is that it is non-magnetic. It is true that prolonged re-heating of manganese steel under certain very limited conditions will render it magnetic but while this is very important and instructive as regards research work it has not been put to commercial use as yet. Therefore in this work the ordinary commercial grade of manganese steel which is non-magnetic will be considered.

The resistance which manganese steel offers to shock and to abrasive action is by far its most important characteristic. Hardness and toughness are in themselves but poor measures of this most remarkable property which may be summed up as "resistance to wear". Point out any particular application where manganese steel castings are being used successfully today and with very few exceptions the reason they are being so used is that they resist wear better than

other materials of proportionate cost. Conversely point out a place where wear is excessive and you have a possible application for manganese steel. It is to be regretted that in many such instances other factors including the properties of manganese steel itself render its use impracticable.

The greatest restriction to the use of manganese steel castings is that they cannot be machined except by grinding which at the best is an expensive proposition. Thus the very properties of hardness combined with toughness which recommend this material also limit its use to rough castings or those requiring a minimum amount of finish. Another restriction is that the heat treatment which changes manganese steel from a brittle to a tough substance cannot be made to extend thru a section thicker than 5½" while 3½" is ordinariarially the maximum section of a well designed casting.

The excessive shrinkage of manganese steel, 5/16" to the foot as compared with 1/8" for cast iron and 3/16" for carbon steel, is another draw-back; not only do all patterns have to be designed for this shrinkage but extra large gates, runners, and risers must be provided and special care must be given to the location of the points of feeding and to the thickness of the channels.

Brief mention will now be made to the essential details in the actual production of commercial manganese steel castings.

III

Manufacture

The various departments essential to the production and sale of manganese steel castings may be listed as follows:

(1) Purchasing Department

(2) Engineering Department

(3) Pattern Shop

(4) Foundry

(5) Steel Works

(6) Heat Treatment Department

(7) Fettling Shop

(8) Machine Shop

(9) Stock Yard

(10) Laboratory

(11) Sales Department

(1) The Purchasing Department is of course necessary to economically procure the comparatively high priced raw products used in the composition of manganese steel, not to mention the great variety of supplies of all kinds which are used in various stages of the manufacture of the completed castings. It may be mentioned here that a much higher grade of supplies of all kinds is used in connection with manganese steel castings than with cast iron or

even ordinary carbon steel castings on account of the comparatively greater value of the finished product. If it becomes necessary to scrap a manganese steel casting the loss is very appreciable principally on account of the total loss of the extra labor which has already been involved and the inability to redeem the manganese when remelting the casting. Therefore, no expense is spared any where along the line in the effort to produce perfect castings.

(2) The Engineering Department must be thoroughly conversant with the characteristics of manganese steel in every stage of its manufacture. Of equal importance is the knowledge of just how the particular casting is to be used in actual practice and what conditions it must meet. The design depends upon both of these factors and is limited by both. The excessive shrinkage of manganese steel means that castings of unequal sections are left after treatment in a state of heavy stress. This may be alleviated to some extent by successive heat treatments but such designs are avoided unless absolutely necessary.

The low thermal conductivity of manganese steel governs the size of the minimum section thru which the metal will flow freely. It is often necessary to allow extra dimensions on certain sections and then remove the excess metal later on by grinding to the correct size. The necessity of changing the metal as originally cast from its brittle state to its tough condition by heat treatment limits the maximum section which can be used. This is accomplished

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to a very large extent by designing the patterns to permit of coreing. Thus the backs of thick jaw plates used in rock crushers are paneled to the necessary depth to permit of correct heat treatment. The Engineering Department must pass upon all such matters and therefore is a vital factor in the production of successful castings.

(3) The Pattern Shop is called upon in practically every instance except in filling duplicate orders where patterns have all ready been made or in shipping from stock. Customers patterns seldom can be used without at least some alterations to allow for the excessive shrinkage of manganese steel and to conform with shop practice. For this reason it is usually preferable for manganese steel founders to furnish their own patterns. Wooden patterns are of course the rule though for small castings made in large numbers such as standard chain links, aluminum models used in connection with molding machines are frequently employed. The Core-making Department may be considered as part of the Pattern Shop and does not differ very much from similar departments in ordinary steel works.

(4) The Foundry is equipped with the usual appurtenances. Molding practice calls for a sand containing a high percentage of silica on account of the severe cutting action of the metal. Dry sand molds are used for all castings except the very light and thin sectioned ones. As it is impossible to drill manganese steel or to cut threads in it, soft steel or wrought iron inserts are placed in

the molds where such work is required and the metal is cast around them. Small key seats require like treatment and in many instances soft steel bushings are cast in to permit machining. Numerous risers are required and great care must be taken as to their proper location and correct dimensions.

(5) The Steel Works consist primarily of special equipment including crucible furnaces for melting the ferro-manganese together with cupolas and Bessemer converters for melting and blowing the low phosphorus pig iron and steel scrap from which the metal is made. The Bessemer Process is particularly adapted to the manufacture of manganese steel for the following reasons:

(a) When Bessemer blown metal is mixed with ferro-manganese to give the desired manganese content of about 12½% the resultant steel contains about the correct percentage of carbon and silicon.

(b) Manganese steel is used largely in small castings and the pouring problems are best solved by the Bessemer process which permits of small heats of high temperature at frequent intervals.

(c) The addition of the large quantity of ferro-manganese necessary to give the correct manganese content deoxidizes the Bessemer blown metal to give the required high quality of steel.

In comparison it may be said that Crucible Melting adds too much carbon to the finished product while the Open Hearth Process is not suitable on account of the large heats to be disposed of and the low temperature of the pouring metal. The Electric Furnace overcomes the enormous loss of manganese caused by the Besse-

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mer method of melting the manganese steel scrap but up to the present time this saving has not been sufficient to offset the high cost of operating an electric furnace.

The standard commercial product of 80% ferro-manganese is carefully weighed and is melted usually in a separate crucible furnace and then poured in the bottom of a large ladle. About 312# of ferro, as it is commonly called, added to a net ton of steel gives 12½% manganese content. The blown metal from the converter is then poured into the ladle to the proper amount and sufficient time is allowed for the manganese to act as a cleanser and thoroughly remove the gases and other impurities from the metal. Chemically speaking manganese has an affinity for oxygen and causes a reduction in the oxides existing in the bath of the material under treatment. This is of extreme importance as it causes manganese steel to be condensed and homogeneous and to be particularly free from blow holes which are so common in other steel castings. The slag is then skimmed off and the metal is poured into the molds. The usual heat is limited to about three tons and therefore an idea of the perfection which has been reached in this stage of the production is realized when it is stated that thirteen ton manganese steel castings are now being successfully produced.

(6) The Heat Treatment Department is one of the most important and until very recently the least understood by an out-

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sider. The early patents on the production of manganese steel covered this particular stage very thoroughly and the manufacturers surrounded the details with the utmost secrecy. As late as 1910 in a paper read before the Association of Engineering Societies this fact is very apparent.

As an illustration of the information, if any that was usually given out the following description of the Sheffield practice in regard to rolled manganese steel castings, taken from V. 50 page 334 A. I. M. E., is to say the least, enlightening:

> "You 'eat it just so 'ot. Then you rowl it to the center, rowl it to the center you understand. If you 'eat it just a little bit too 'ot, you crush your ___ ingot. If you don't 'eat it quite 'ot enough, you break your --- rowls!"

As previously stated manganese steel as originally cast is extremely hard and brittle. This is fortunate in one way as it permits the risers and gates remaining on the castings when taken from the molds to be broken off, work that could only be done at great expense were the castings as tough as they are in their final condition. The untreated brittle castings are placed in annealing furnaces and gradually heated in the most careful manner. This work is guaged with high-grade pyrometers and other instruments. The temperature ranges from 1600 F to 2200 F, and the time allowed for the casting to remain in the furnace varies from three to twenty-six hours both factors depending on the nature of the piece

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being treated. After receiving the correct amount of annealing the castings are taken from the furnace and while still red hot are suddenly immersed in cold water. The necessity for the care taken in the design of the distribution of metal especially in large and intricate castings is now apparent. It is necessary that all of the parts cool at approximately the same time else this drastic action of sudden water cooling will cause uneven contraction which must result in cracking the casting.

(7) The Fettling Shop might very well be called the buffer between the producer and the user of so called"rough castings". A casting may be properly designed, cast, and heat-treated, but unless it is "touched up", or in other words, fettled, it is quite possible that it can not be used by the buyer. This is due to the fact that manganese steel can not be commercially machined by any known cutting tool and is almost file hard. The least projection in castings may prevent a perfect fit and,if the expression will be permitted, cause "a perfect fit" on the part of the mechanic supervising the installation. As a matter of fact the popularity of a certain make of manganese steel castings over all other makes in this country may be traced directly to the extra work done by this department. Every casting is subjected to a rigid inspection and is sent out true to pattern with rough spots removed. In other words, these castings "look good" and the value of such an appear-

ance cannot be overestimated from a selling standpoint, which after all is the final criterion. A casting is not a good casting unless it can be sold all strictly producing authorities to the contrary. The essential function of the Fettling Shop, therefore is to do the rough grinding, usually by means of portable emery wheels, which is required on rough castings before they are shipped or placed in stock and on finished castings before they are sent to the machine shop.

(8) The Machine Shop contains many varities of grinding machines most of which have been designed for the particular class of heavy duty required in connection with manganese steel. Castings are turned out as nearly true to dimension as possible for every fraction of an inch which must be removed by grinding means an added expense in time, labor and material. The cost of this work is naturally much higher than similar machining on castings which can be finished with cutting tools. Never-the-less it is frequently necessary to remove from 3/8" to 1/2" of metal on a side particularly where large diameters are involved. In such cases specially designed grinders with multiple grinding heads can be used to advantage. Coarse grained grinding wheels are used for what may be termed "rough cuts" and finer ones for the finishing touches. It is possible to obtain very accurate calibrations by grinding, but such work is expensive and is usually avoided if possible by the manufacturers.

(9) The Stock Yard is a very necessary adjunct because in many instances manganese steel castings are required for break down jobs and the many stages in the manufacture as herein described must be gone thru in regular order and cannot be unduly rushed. The average promise of shipment on an order where the parts must be cast is three weeks after receipt of order and full information at the works. If it is necessary to construct patterns or do an excessive amount of machine finishing this time is liable to be exceeded. Therefore, where possible standard castings which are frequently ordered are carried in stock.

In some cases this has proven an expensive policy because a slight alteration in specifications may render the castings on hand utterly useless. A case of this kind which was narrowly averted came under the personal notice of the writer. A set of coal breaker segiments with holes and countersinks for 7/8" square headed bolts was placed in stock after this particular pattern had been used for several years by one of the largest Anthracite Coal Companies. These bolts had given some trouble by shearing and the next order specified holes for 1-1/8" bolts. The diameter of the holes could have been enlarged but the square countersinks for the heads of the bolts could not be touched. Permission was finally received to ship this one set to be used with the smaller bolts and the pattern was then altered to allow for the larger ones. This illustrates one of the many difficulties met with in handling a

product which is not effected by ordinary procedure.

(10) The Laboratory not only supervises the different stages in the manufacture of manganese steel castings but it is also the Court of Last Appeals. Frequent analyses are made of the raw material used, the cupola metal when it is melted and the blown metal. Every heat is carefully analyzed and a record kept of the same. This is absolutely necessary in order to maintain the uniformity called for in such high grade material as manganese steel. The records of the annealing furnaces are kept by this department and the duration and extent of the last treatment necessary for particular castings are determined here. Furthermore if there is anything wrong with a casting either before or after being put in service the Laboratory is at once called upon to make a thorough chemical and physical examination to determine the cause of the trouble. Nothing can escape these scientific investigations. Incorrect heat treatment is responsible for most of the failures and a microscopic examination of the structure of the casting in question clearly indicates such a fault. It is usually possible to trace a particular casting back to the heat from which it was made by means of the order number on which it was furnished and the complete records of this heat are then available. The Laboratory also offers an opportunity for research work in regard to this interesting steel alloy which has resulted in many of the advances made in the industry in the

last quarter of a century.

(11) The Sales Department is responsible for the commercial use of manganese steel castings. The enormous demand for this material at the present time has not grown over night but has been created and fostered by intelligent salesmanship. The men who are doing this work now are for the most part graduate engineers who are made thoroughly familiar with the characteristics and problems relating to manganese steel by an extensive apprentice course in the various shops and particularly in the Engineering Department previously described. The selling price of manganese steel castings depends roughly on the weight and the design, the latter including the difficulties of casting and the amount of machine work required. A very rough estimate of the price of a medium weight casting with little or no machining may be placed at ten cents per pound. A similar casting in ordinary steel would cost about five cents and in cast iron from two to three cents per pound. In many cases the ratio will be even greater. This is the first great problem the salesman must solve. There are many answers. If a manganese steel casting costs five times as much as the one it replaces the chances are that it will wear ten, perhaps twenty times as long. Even if it lasts but five times as long - and compared with cast iron this ratio of the wearing qualities in abrasive actions is conservative - there is a saving of four installations. If the casting to be replaced has failed by breaking, as is frequently the case with cast

iron, the solution is easier, for manganese steel castings very seldom break.

The difficulty of introducing a new substance has been another great problem to the salesman. The old familiar excuse, "We have got along so far very well with so and so. Why should we change now?" is still heard although it can now be answered as it could not in the early days, by submitting definite results of tests on similar installations. The salesman is always willing to back up his statements with the offer of a trial. When the Taylor-Wharton Iron and Steel Company, who first introduced manganese steel in this country, started to promote and push the use of manganese steel conveyor and elevator chain, they furnished free, large numbers of ten foot sample lengths of chains dipped in red paint for identification and the salesmen saw that these samples were included in lines of similar chain where the wear was rapid and severe. Before long the ordinary chain had to be renewed but it was noticed that the red ten foot length was not worn out. It therefore was used again in making up the complete line. When this sample length of manganese steel chain had out-worn five sets of malleable iron chain and was still in first class condition, it was not very hard to convince the superintendent that it would pay him to have this whole line furnished in manganese steel.

It is necessary for the salesman to know just when to recommend an installation of manganese steel. The argument of

greatly increased life of the casting loses much of its force if the material being used lasts say a year or more. In such cases it usually does not pay to go to a great initial expense when the economy would not begin to be felt until a number of years later. In some cases where cast iron is being used and replacements while frequent are made during regular shut-downs it is also difficult to show economy especially in view of the fact that cast iron scrap is turned back to the founders for as much as 25% or more of the original cost while manganese steel scrap on account of the loss of the manganese content when remelted and blown is only worth about 5% of the original cost.

It is poor policy to recommend an installation that will not be economical and the efforts of the Sales Department are therefore confined to the following general classes of work, which cover every application of manganese steel castings without exception;

(a) Installations where failure of less dependable material will endanger life or property.

(b) Installations where the cost of shut-downs for replacements amount to more than the difference in the first cost of the repair parts.

(c) Installations where the difference in the life of the castings outweighs the difference in first costs.

(d) Installations where the inherent properties of manganese steel give better results than any other material.

A peculiar feature regarding manganese steel castings

and one that necessitates fundamental engineering knowledge on the part of salesmen in that practically all of the applications are for parts of machines or products of someone elses manufacture. In other words, the governing dimensions of most repair parts which are now made of manganese steel are determined usually for a different material by the manufacturer of the machine or contrivance using such parts and naturally this manufacturing information is jealously guarded by him. The salesman is called upon to furnish this information by means of complete sketches unless the casting to be replaced can be sent direct to the works which is usually impossible. A slight change in the design of a part by the manufacturer of the machine means that corresponding changes are necessary in castings for all machines of this later model. Bitter experience has taught all concerned with manganese steel castings to adopt the creed: "There are no such things as standard dimensions!"

The difficulty of lack of manufacturing information and the prejudice against a new product are both very much less now than they were a few years ago as the pioneer work in the introduction of manganese steel has been accomplished. There are still serious obstacles to overcome in many instances but the advantage of using manganese steel castings in certain applications are thoroughly understood and granted now by well informed users. The more important of these applications will be considered in the next chapter.

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IV.

Applications.

The more important applications of manganese steel castings will be considered under the following headings:

(1) Steam Shovel Parts.

(2) Hydraulic Pump and Sand or Gravel Dredge Parts.

(3) Gold Dredging Parts.

(4) Crushing and Pulverizing Machinery.

(5) Screening Apparatus.

(6) Coal Breaker Parts.

(7) Wheels.

(8) Sheaves and Rollers.

(9) Gears and Pinions.

(10) Chains and Conveyor Parts.

(11) Cement Mill Parts.

(12) Iron and Steel Mill Parts.

(13) Safes and Vaults.

(14) Track Work.

(1) Steam Shovel Parts.

The Panama Canal was dug by manganese steel castings. This statement is made advisedly and is in strict accordance with the facts. One of the most important uses of manganese steel is for the wearing parts of Steam Shovels and dipper dredges. The dipper itself and particularly the teeth at its cutting edge must bear the brunt of the shocks and strains and most severe abrasive action resulting from work of this character. Manganese Steel is better suited for such requirements than any other material, a fact early appreciated by the manufacturers and illustrated by the fact that every steam shovel working on the Panama Canal and nearly 90% of the steam shovels in the United States are equipped with such parts.

The most popular design of dipper tooth called the Panama Tooth consists of a base which is riveted to the dipper and a removable point which is bolted to the base. Different views are shown by Fig. 1. This is an instance where a shut-down on account of breakage or replacements is very expensive. The two-part tooth was designed to minimize this lost time as most of the wear is on the point and a set of points can be changed in half an hour where formerly with a solid tooth a much longer period was required to cut and re-rivet the entire tooth. Fig. 2 shows a modification of this design known as the Panama Reversible Dipper Tooth. A point

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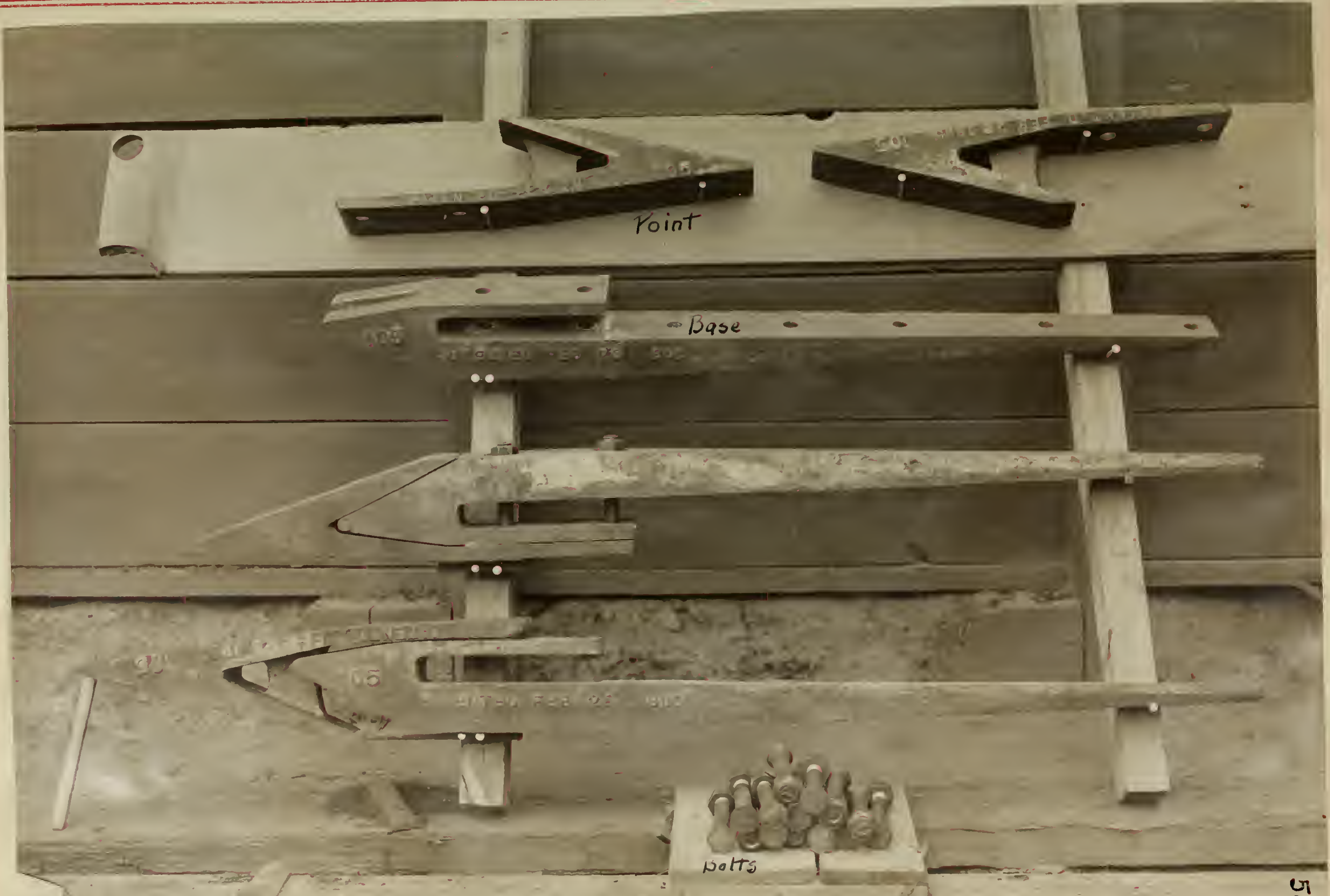

Fig. 1. Panama Dipper Teeth.

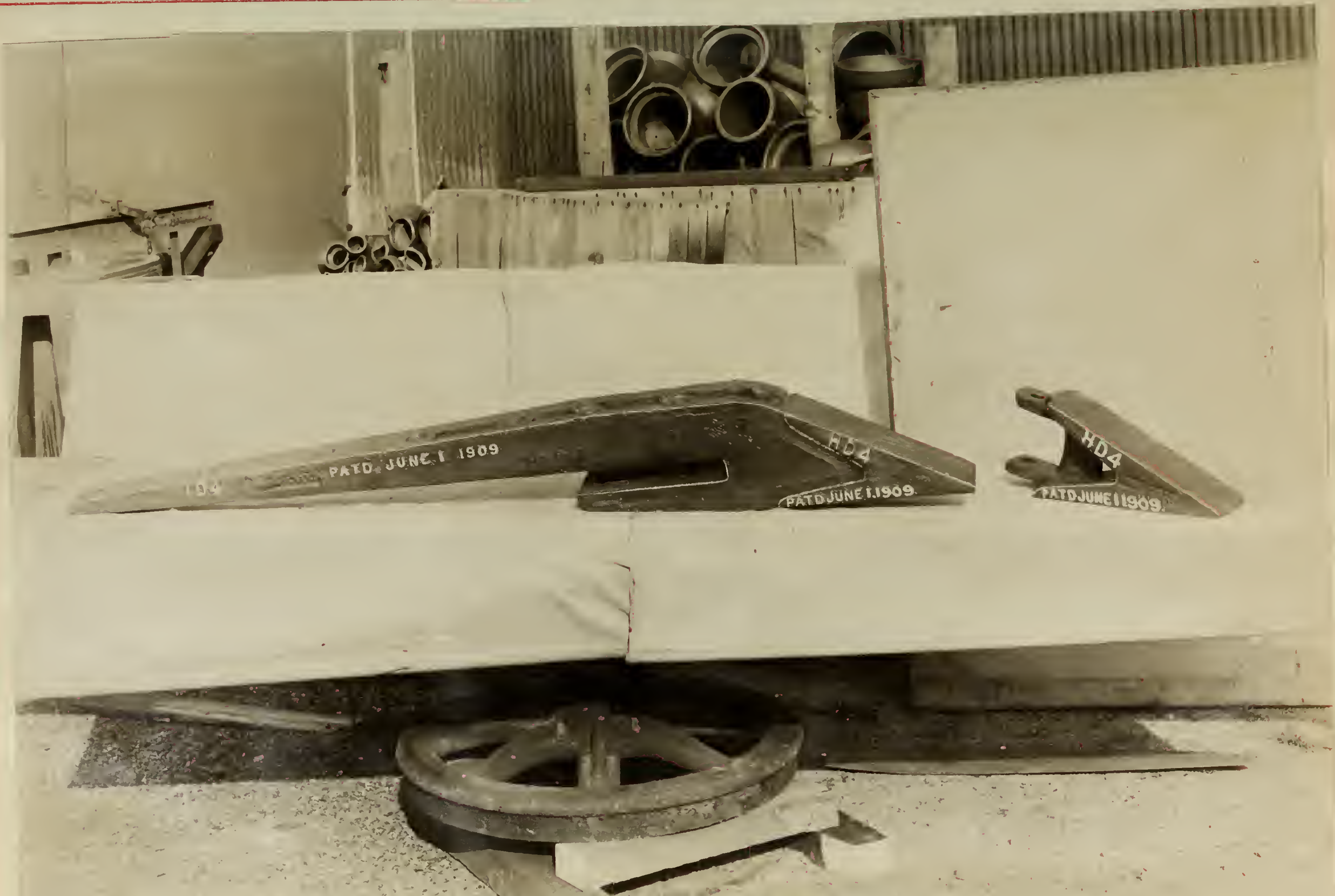

Fig. 2. Panama Reversible Dipper Tooth.

usually wears most on the under or cutting edge. As sharp points are essential for rapid and economical digging especially in dirt or gravel, the ordinary point is sometimes discarded before being worn all the way down because it has become dull. The reversible design as may be seen from the photograph is symmetrical around a center line so that when one edge becomes dull it may be turned thru 180 degrees and a new sharp edge be thus obtained.

The old style dipper was of a built up design and manganese steel lips at the cutting edge were frequently used. This led up to the solid manganese steel front which is now used with much better results. Other parts of the dipper which are often made of manganese steel are the hinges, hinge brackets, bails, bail brackets latches and latch keepers. Fig. 3 shows the front view of a large dipper of manganese steel construction and Fig. 4 shows the rear view. The principal parts are indicated on these photographs. A few solid manganese steel dippers have been made with every part manganese steel except the rivets. This seems a needless expense as some parts such as the doors, back castings, etc. can be made of cheaper material and will still last as long as the rest of the dipper where the wear is more severe. A new design of solid front has front and bases cast integral thereby eliminating rivets and increasing rigidity. A disadvantage with this design is that if anything happened to the stub of the base projecting from the front, the entire casting would be made useless.

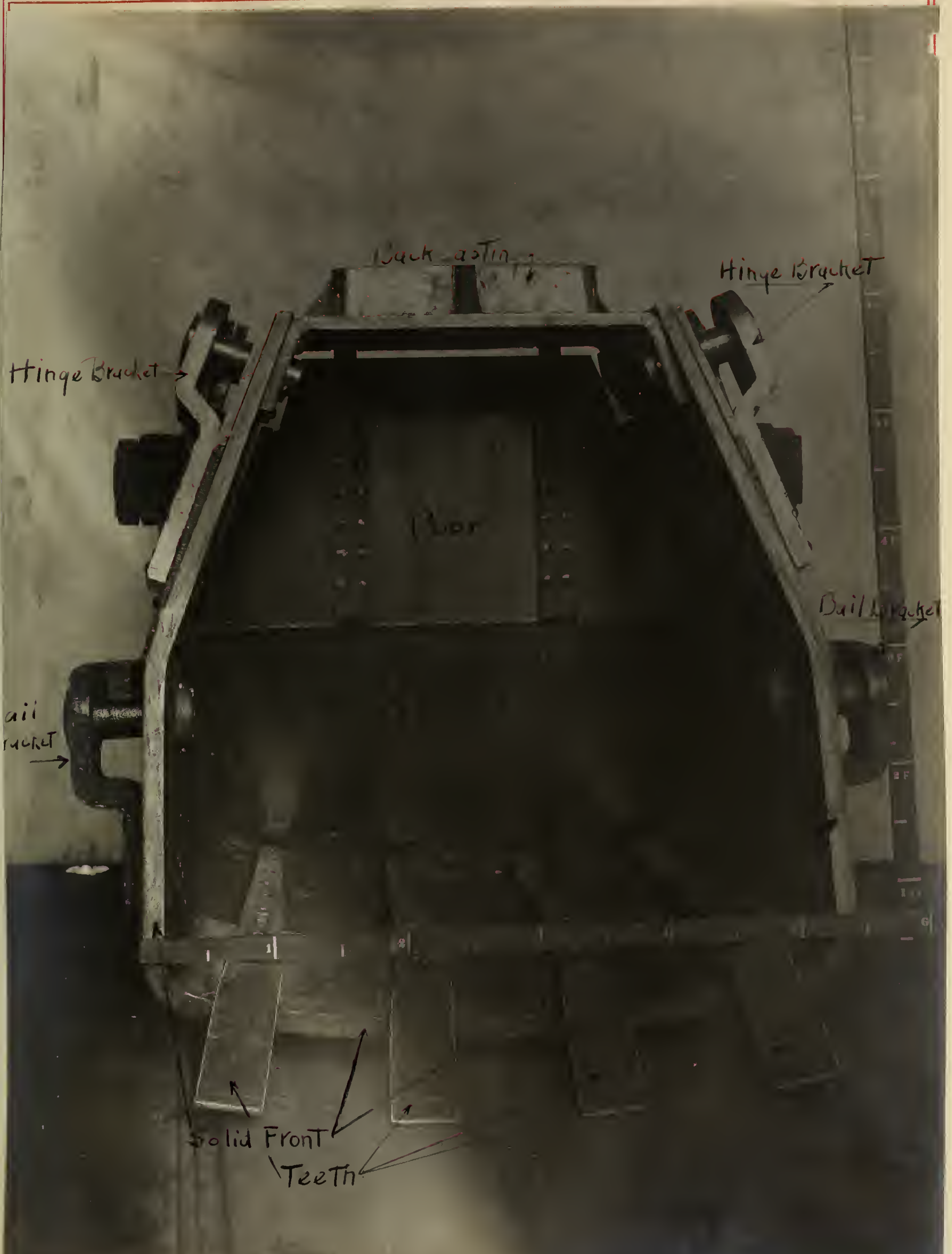

Fig. 3. Dipper - Front View

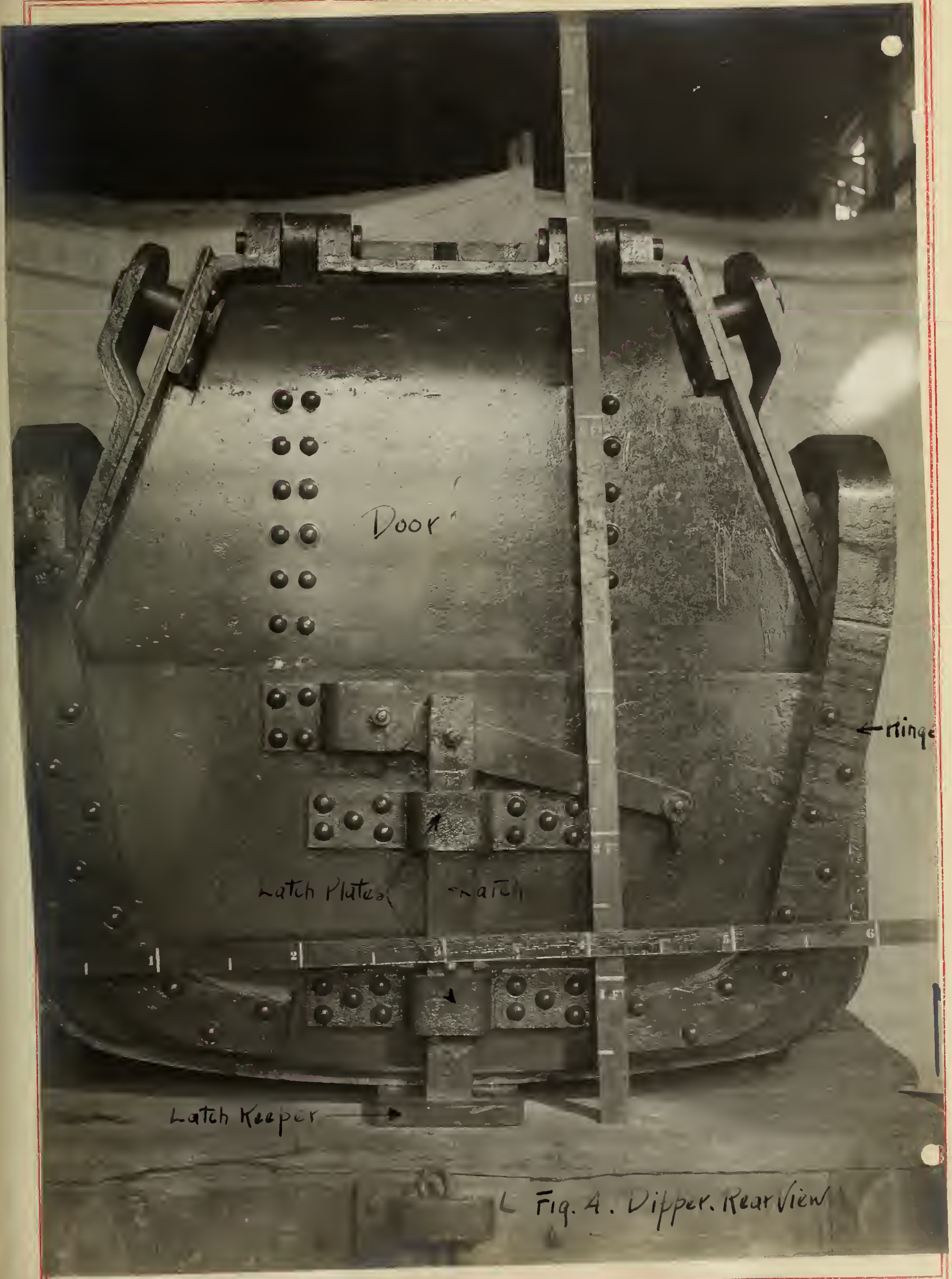

Fig. 4. Dipper. Rear View

The racks and racking pinions on steam shovels are very good applications of manganese steel. Sample of the castings are shown by Fig. 5. Shipper shaft pinions especially for square shafts are very difficult to machine as an emery wheel cannot grind a square corner without leaving about a 3/16" fillet. This is not permissible with these castings and therefore an offset is made in each corner by coring so that the square bore can be finished up to this offset. The manufacturers have usually lost money on such castings and are not pushing the sale of them. Sheaves, winding drums, saddle plates, etc. are further possible applications on steam shovels but it is questionable if such high grade and expensive material as manganese steel is necessary or economical. In this connection it may be said that the wonderful results obtained by the use of manganese in some applications has lead to the erroneous idea that it is a "panacea" or "cure-all" for all steel casting troubles. Naturally the inherent properties of other metals make them better suited for particular uses and it is gratifying to know that from the very first the policy of the more reliable manganese steel founders has been to recommend their steel only where it is best adapted to resist heavy wear and breakage and where it will prove economical. Any other policy will work to the detriment of the industry in general and the particular manufacturer who promotes wrong uses in particular.

Fig. 5. Rack and Racking Pinion.

(2) Hydraulic Pump and Sand or Gravel Dredge Parts.

The wearing parts of centrifugal pumps handling gritty material such as sand or gravel are very good applications of manganese steel. Other material wears out rapidly in such instances but the great toughness of manganese steel resists for a long time even such severe abrasive action as this. Fig. 6 shows one of the largest manganese steel pump casings or shells that has ever been made. The sides of the casing and face of the discharge opening are shown machine finished with holes drilled in soft steel inserts which were cast in at the proper intervals on the peripheries. Fig. 7 shows a smaller casing with the runner or piston which fits in it and liners or disks which fit on the sides. The pulley side is shown in place. A different design of bolt holes is shown in this photograph and in Fig. 8 which does not necessitate the use of soft steel inserts. Fig. 9 gives a close view of a runner, Fig. 10 shows a casing made in two parts to facilitate installation and Fig. 11 shows how the parts are assembled for use. A large manganese steel pipe section is shown by Fig. 12.

For sand or gravel dredges ditching machines and drag-line excavators the wearing parts such as cutter heads complete including knives, wearing plates, links, tumblers, bucket lips, teeth, liners and many other special parts most of which will be considered under future headings, may all be considered good applications for

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Fig. 6. Pump Casing.

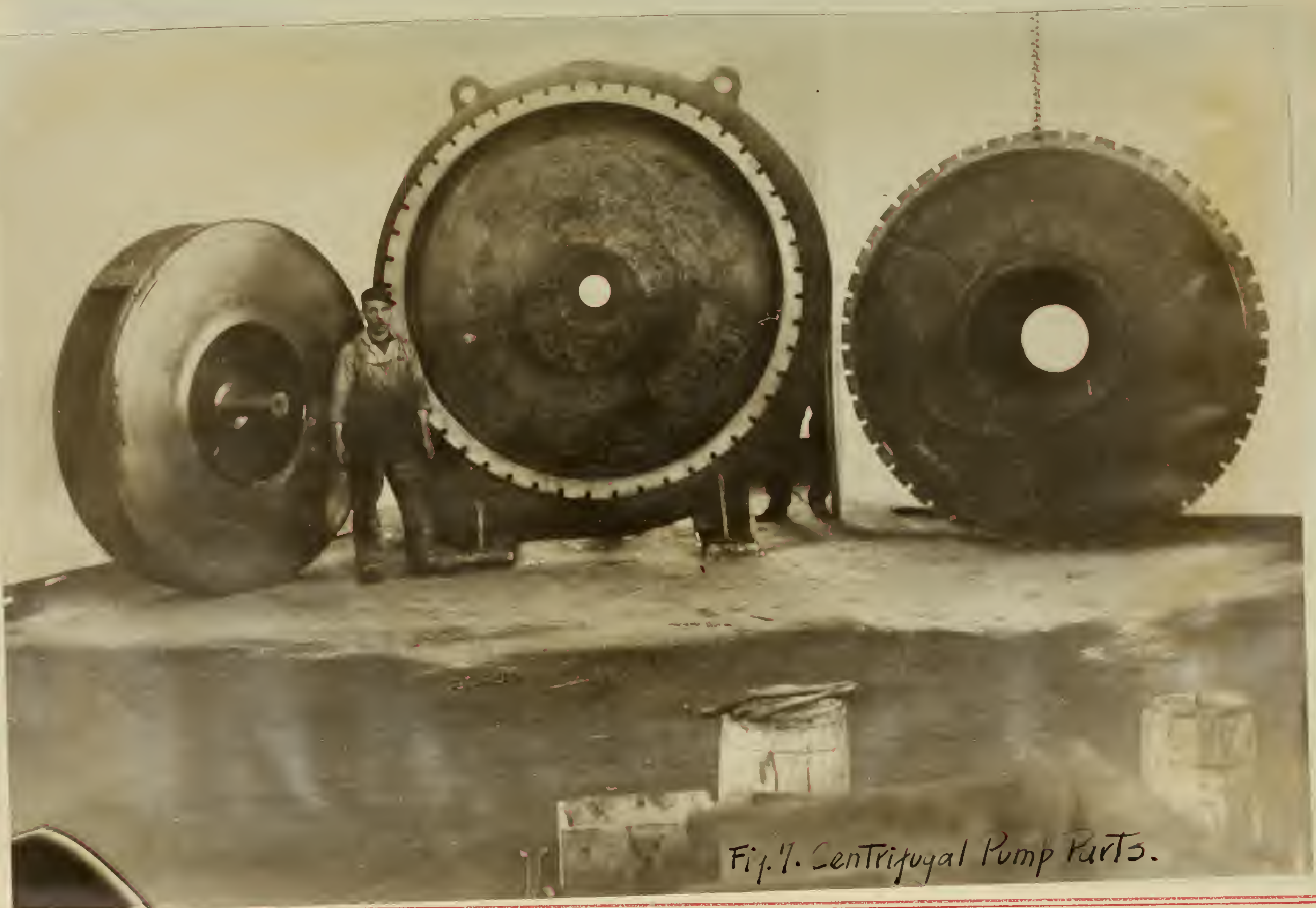


Fig. 7. Centrifugal Pump Parts.

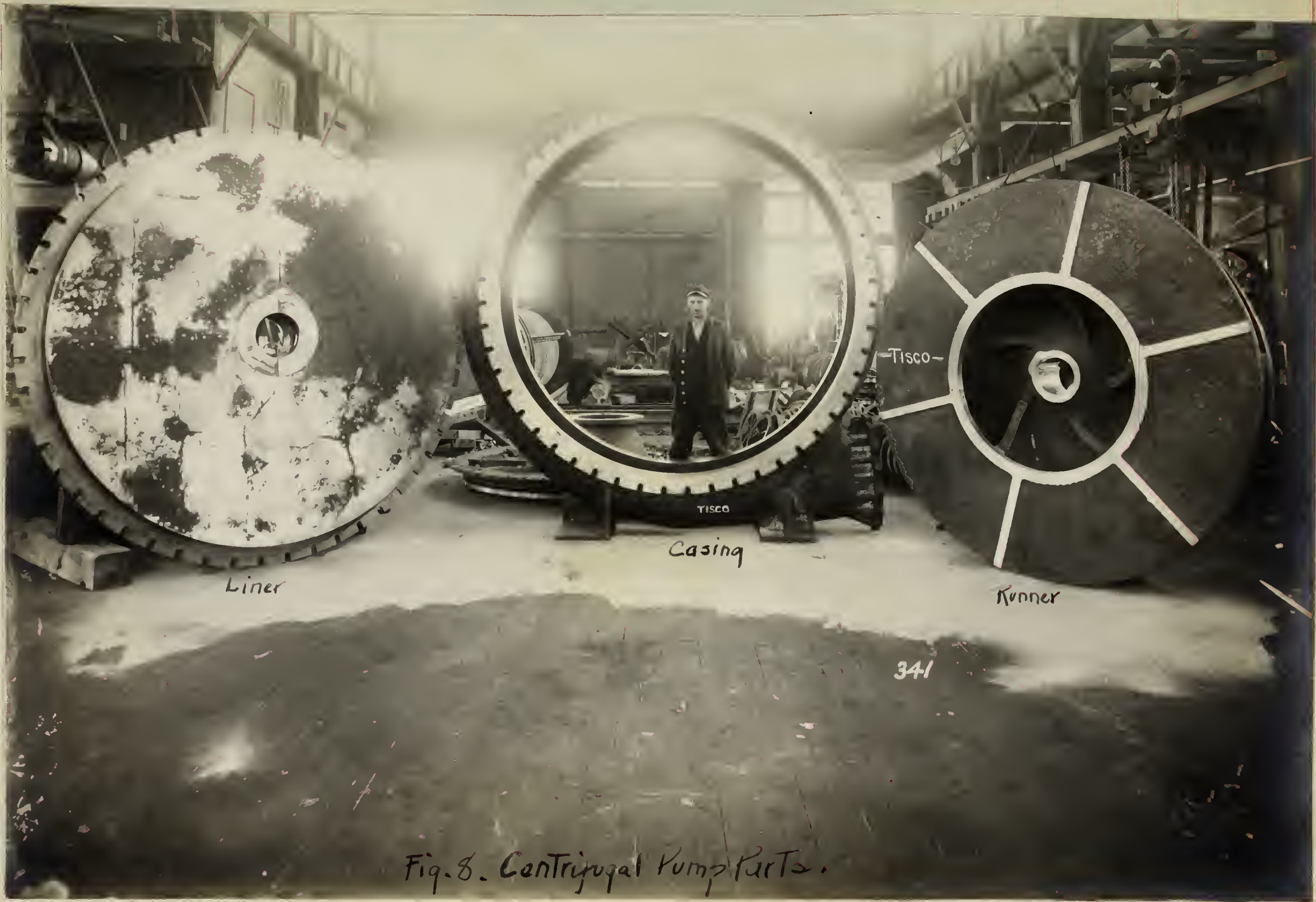


Fig. 8. Centrifugal Pump Parts.

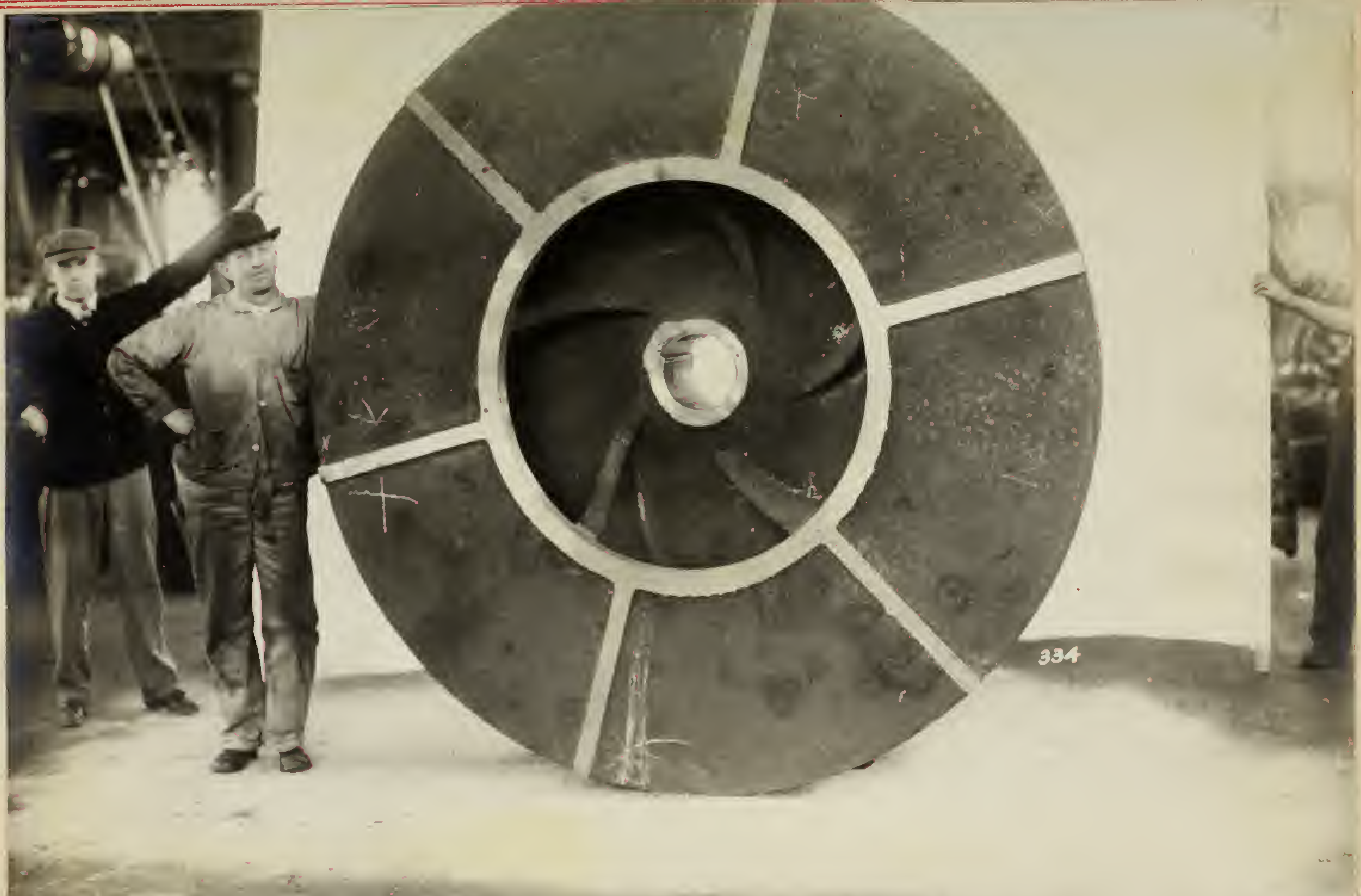


Fig. 9.. Pump Runner or Piston.

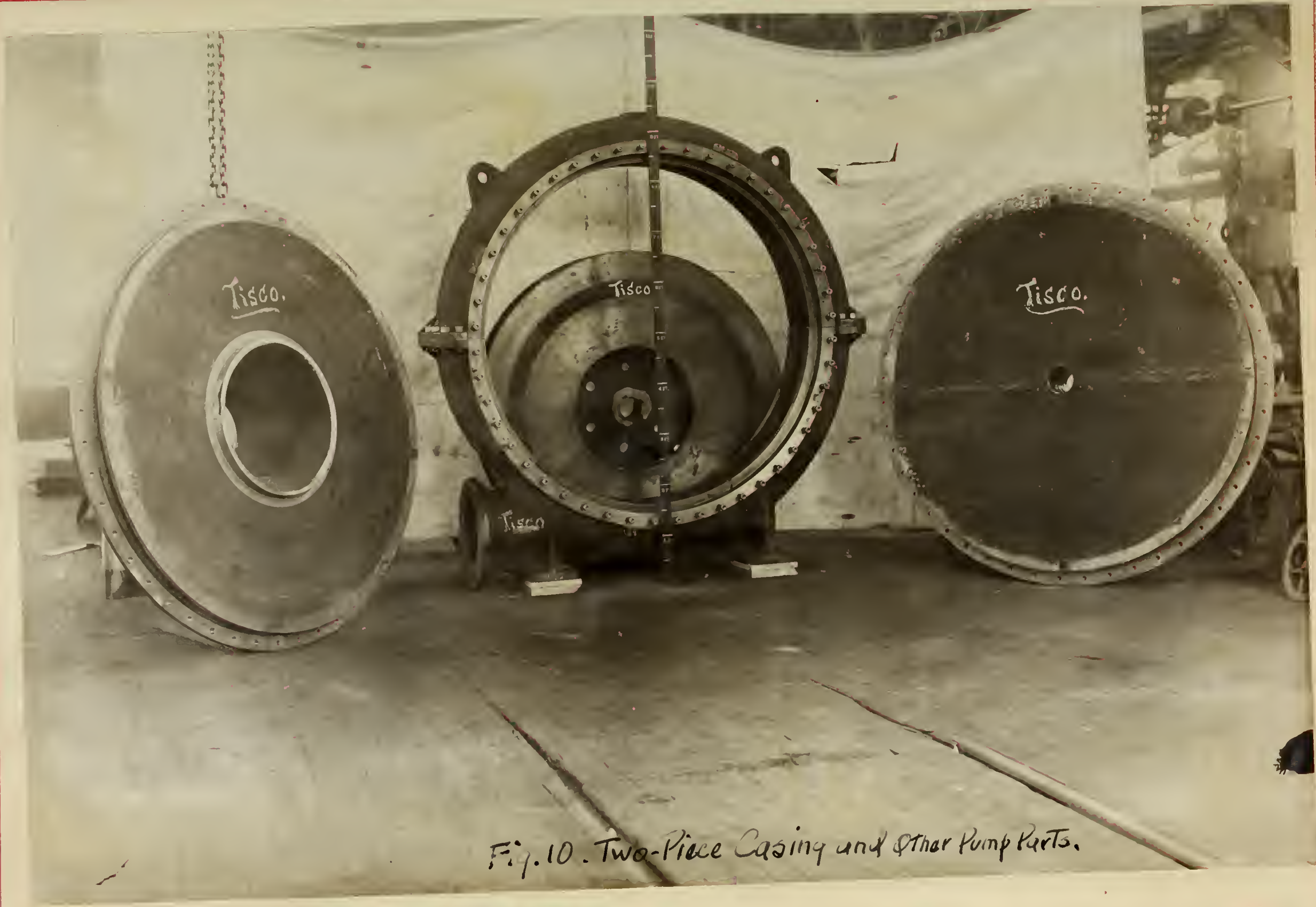


Fig. 10. Two-Piece Casing and Other Pump Parts.

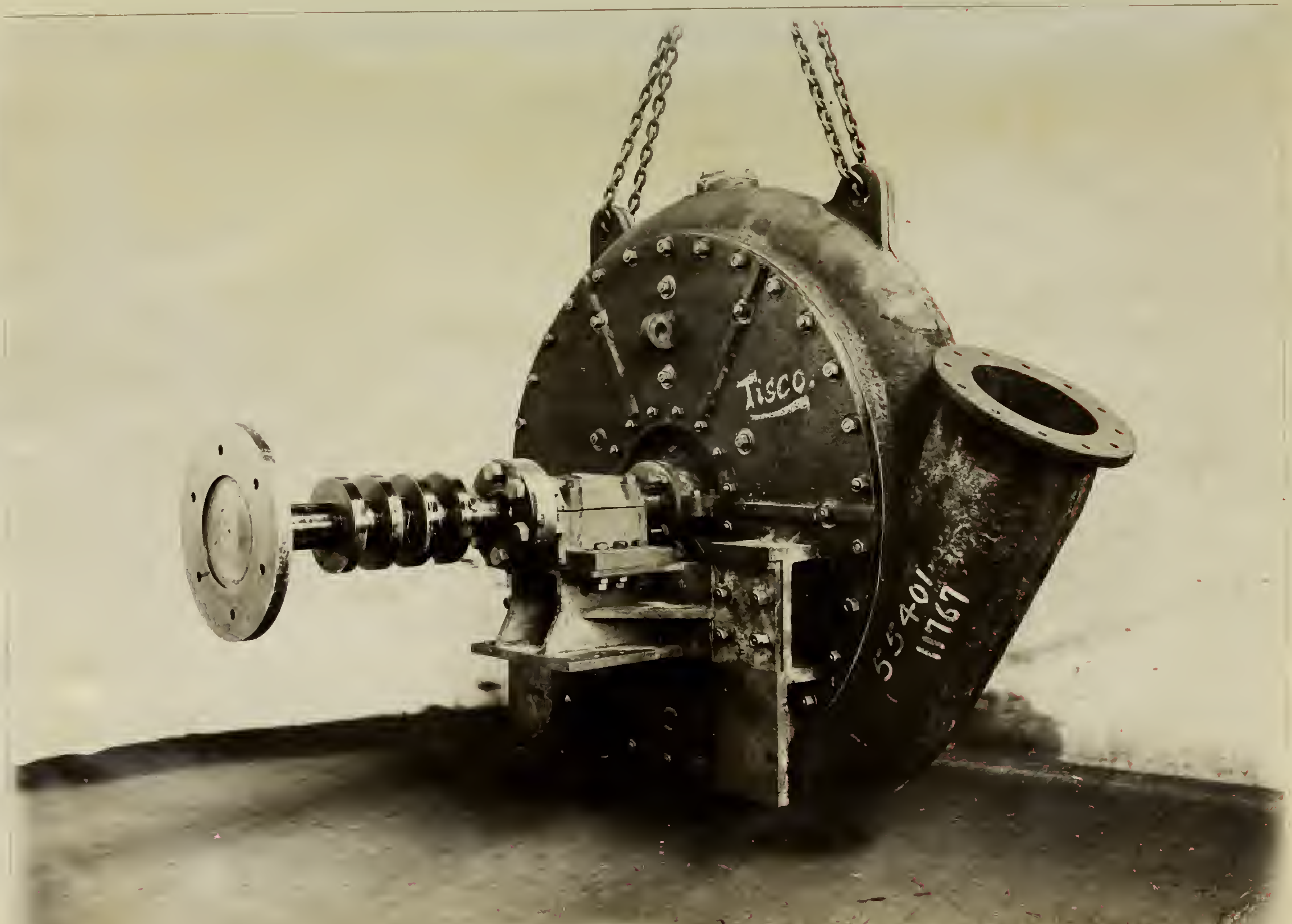


Fig. 11. Pump Parts Assembled.

Fig. 12. Pipe section.

manganese steel castings. Fig. 13 shows a cutter head with knives in place and Fig. 14 shows a similar casting of different design.

(3) Gold Dredging Parts.

Some of the largest orders in point of tonnage which the manganese steel founders have received have been for placer dredge buckets in the gold dredging districts of the far west and elsewhere. Several car loads of such castings are shown by Fig. 15. Manganese steel is very suitable for this class of work where there is a continuous severe abrasive action. Fig. 16 shows a 2 cubic yard bucket with lip riveted on. Fig. 17 shows a different designed bucket illustrating the thickness of the lip and also the manganese steel bushing which is placed at the back eye. This may be renewed as the wear at this point both on the outside and the inside is very severe. In order to avoid leakage and loss of the very valuable material these dredge buckets convey from the pond to the upper tumbler, the bottom and hood of most buckets are now cast integral, rivets only being required to fasten on the lips.

Tumbler wearing plates, including tread plates, check plates, ear plates, tip plates, etc. are all made of manganese steel as are also the tumblers themselves as shown by Fig. 18. These are furnished with a ground bore and weigh as much as twelve tons.

(4) Crushing and Pulverizing Machinery.

Fig 13 – Dredge Cutter Head.

Fig. 14. Dredge Cutter Head.

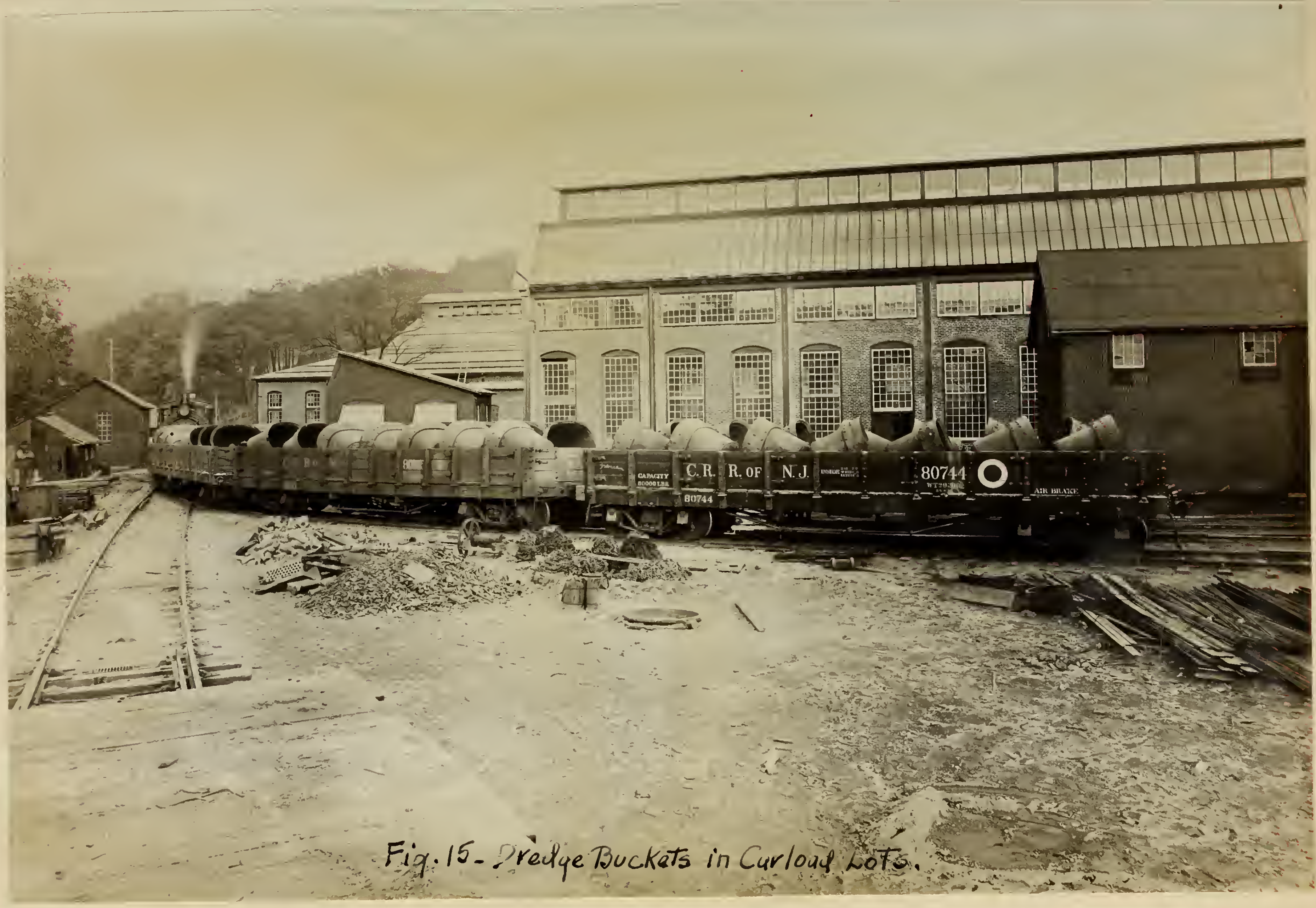
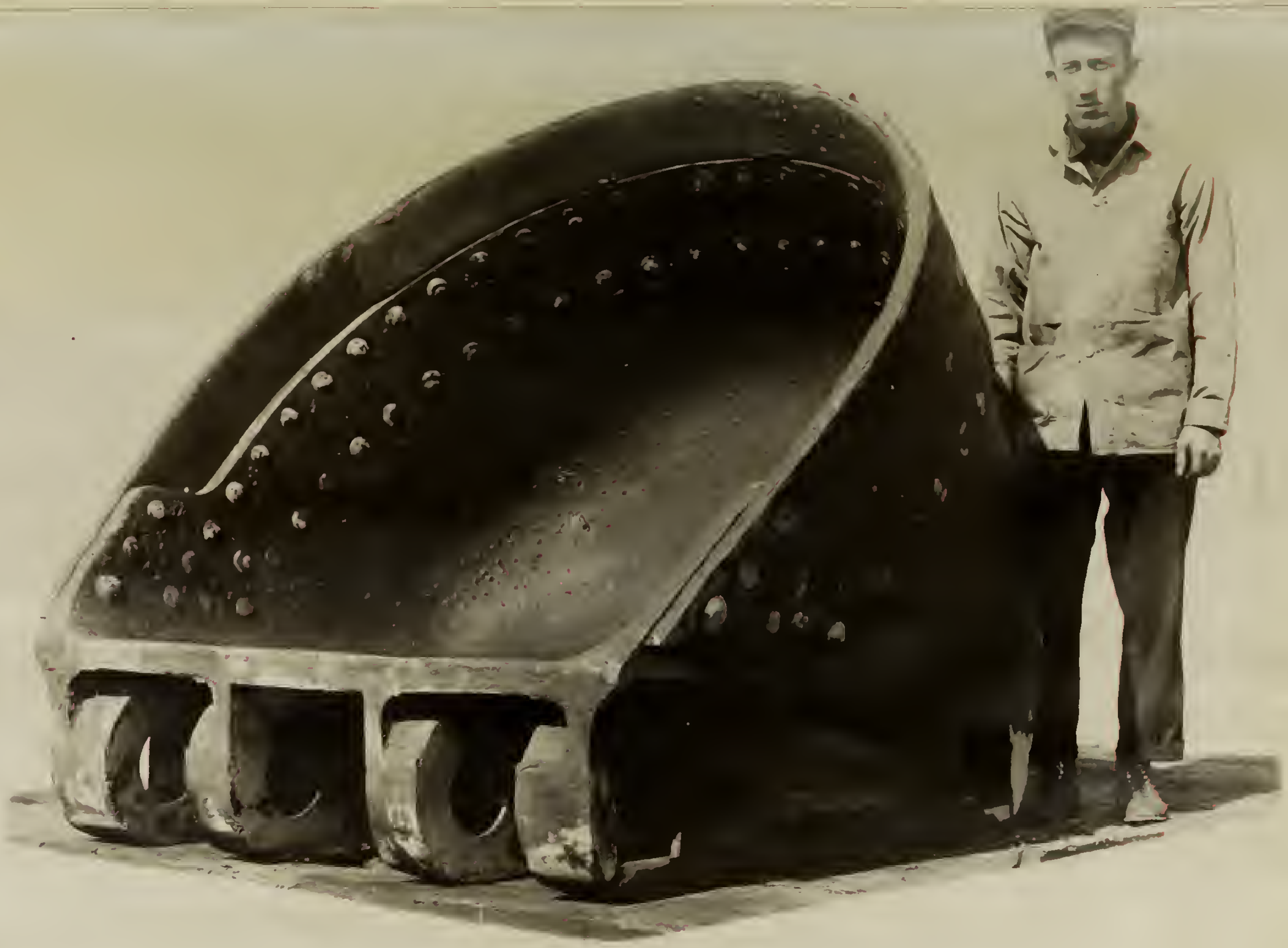


Fig. 15 - Dredge Buckets in Carload Lots.



TAYLOR WHARTON IRON & STEEL CO.,
~ 2 CUBIC YARD BUCKET. ~

Fig. 16. Placer Dredge Bucket.

Fig. 17. Dredge Buckets.

Fig. 13. Gold Dredge Tumbler

The applications considered here-to-fore have all been connected with apparatus designed to remove material from its natural location on the earth's surface to some other point. The breaking up and reducing of material will now be considered. Rock crushers of both Jaw and Gyratory types are very common and the wearing parts for them were one of the first widely known applications of manganese steel. The resistance to shock as well as to abrasive action comes into play here. For Jaw Crushers the following parts will prove economical: jaw-plates, cheek plates, toggle plates and toggle bearings. Fig. 19 shows a number of such castings.

For Gyratory Crushers, heads, mantles, concaves, and in some instances, chutes, wearing-plates, gears and pinions are good applications for manganese steel. For small crushers solid heads are recommended while for large ones a cast iron center with a manganese steel mantle is more economical. This center is bored and key-seated to fit the shaft and finished on the outside. The manganese steel mantle fits over and is zinced to the center and when worn out a new mantle can be used in its place. The relative sizes of such castings are very well shown by Fig. 20. Concaves are furnished either in one or two-piece designs of the required thickness. They are paneled to reduce weight and permit correct heat treatment especially in the larger sizes. As most of the wear comes at the lower part of the concave the two-piece design is ordinarially preferred as only the lower section need be renewed.

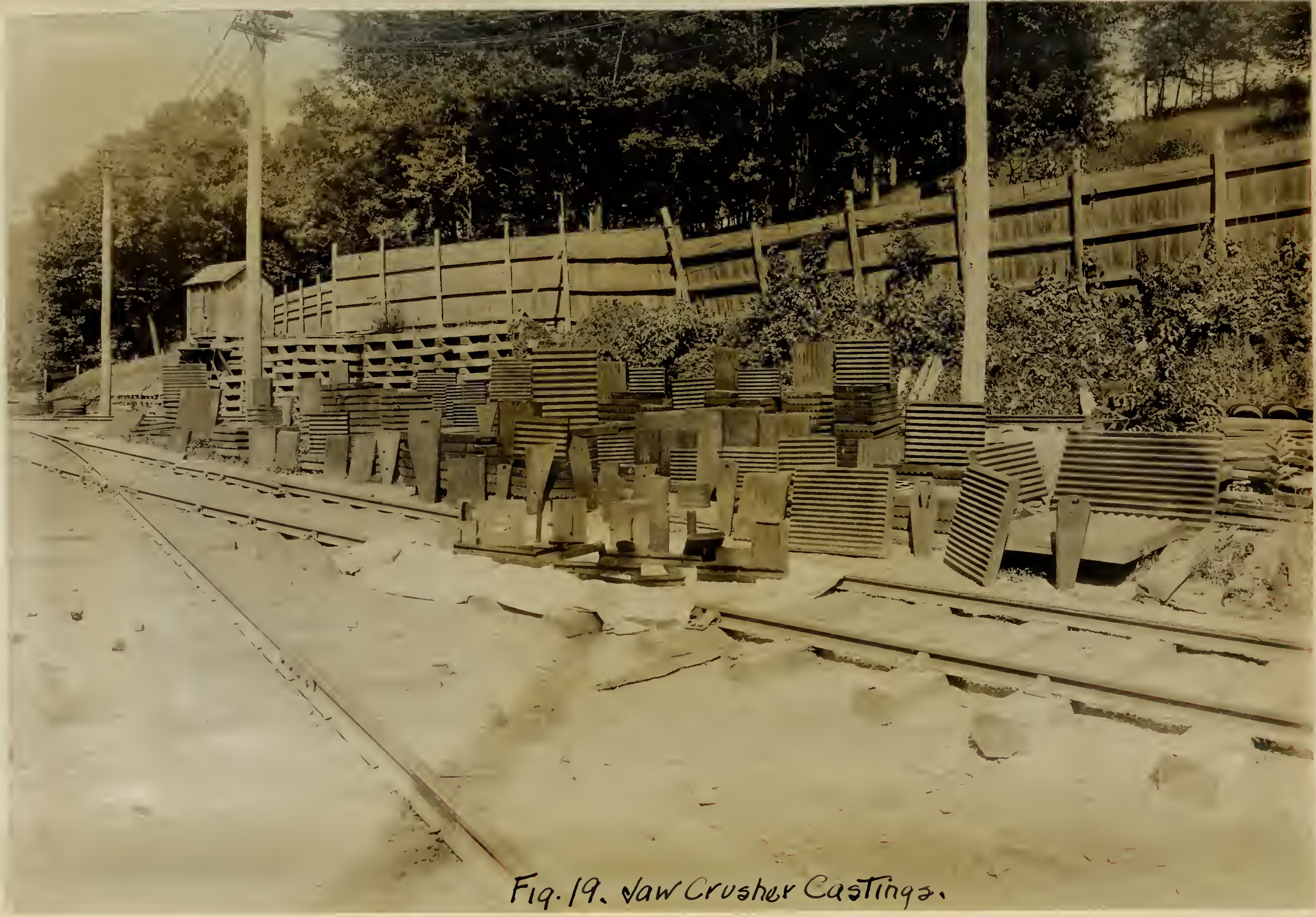


Fig. 19. Jaw Crusher Castings.

Fig. 20 - Gyratory Crusher Parts.

Rotary Crushers and Pulverizers use manganese steel hammers, screen bars, and screen plates, the hammer being a particularly good application. Several designs of screen bars are shown by Fig. 21.

Clay Products Machinery wearing parts which are sometimes made of manganese steel include gears and pinions, screen plates, muller rims or tires, tread plates and pug mill knives. The knives have practically been demonstrated to be a misapplication and in fact all parts in wet grinding may or may not prove economical. One reason for this is that the slip between the rollers and the bottom of the pan causes heavy torsional strains which manganese steel is not specially fitted to withstand. The wearing parts of emery mills, sample grinders, stamp mills and similar apparatus including the rolls, sledge hammer, cones, dies, liners, wearing plates, etc., are possible applications of manganese steel but the advantages of this high priced material usually are not as apparent as in the other applications mentioned under this general heading.

(5) Screening Apparatus.

After crushing or pulverizing different materials it is usually necessary to separate the different grades by screening. If the material is very hard or gritty such as trap rock or granite manganese steel screens will prove economical. Screen plates offer

Fig. 21. Screen Bars for Crushers or Pulverizers.

difficult casting problems and are usually made in sections of four or six segments to the circle. They are generally cast 5/8" to 3/4" in thickness depending on the inside diameter of the screen or in other words, the area of the plate. The minimum diameter of hole is about 5/8" on the outside. Holes are usually tapered to facilitate discharge, something that can be done with castings, which is difficult to accomplish in punching. A complete screen with all wearing parts such as screen plates, tires, rollers, discharge chute, sprocket chain, gears and pinions made of manganese steel is shown by Fig. 22. A different design of friction driven screen is shown by Fig. 23. Grate bars and grizzle bars for stationary screens handling ore are widely used and give very great satisfaction.

Manganese steel chutes in general may be considered under this heading. If the wear is severe they will prove economical for they will wear very much longer than other material but as an ordinary cast iron or sheet steel chute usually lasts a long time the service has to be very severe to warrant the installation. In ore handling this is often the case.

(6) Coal Breaker Parts.

The use of manganese steel rolls and segments in the Anthracite Region is almost universal. In breaking coal to prepared sizes it is of the utmost importance to crack the coal without

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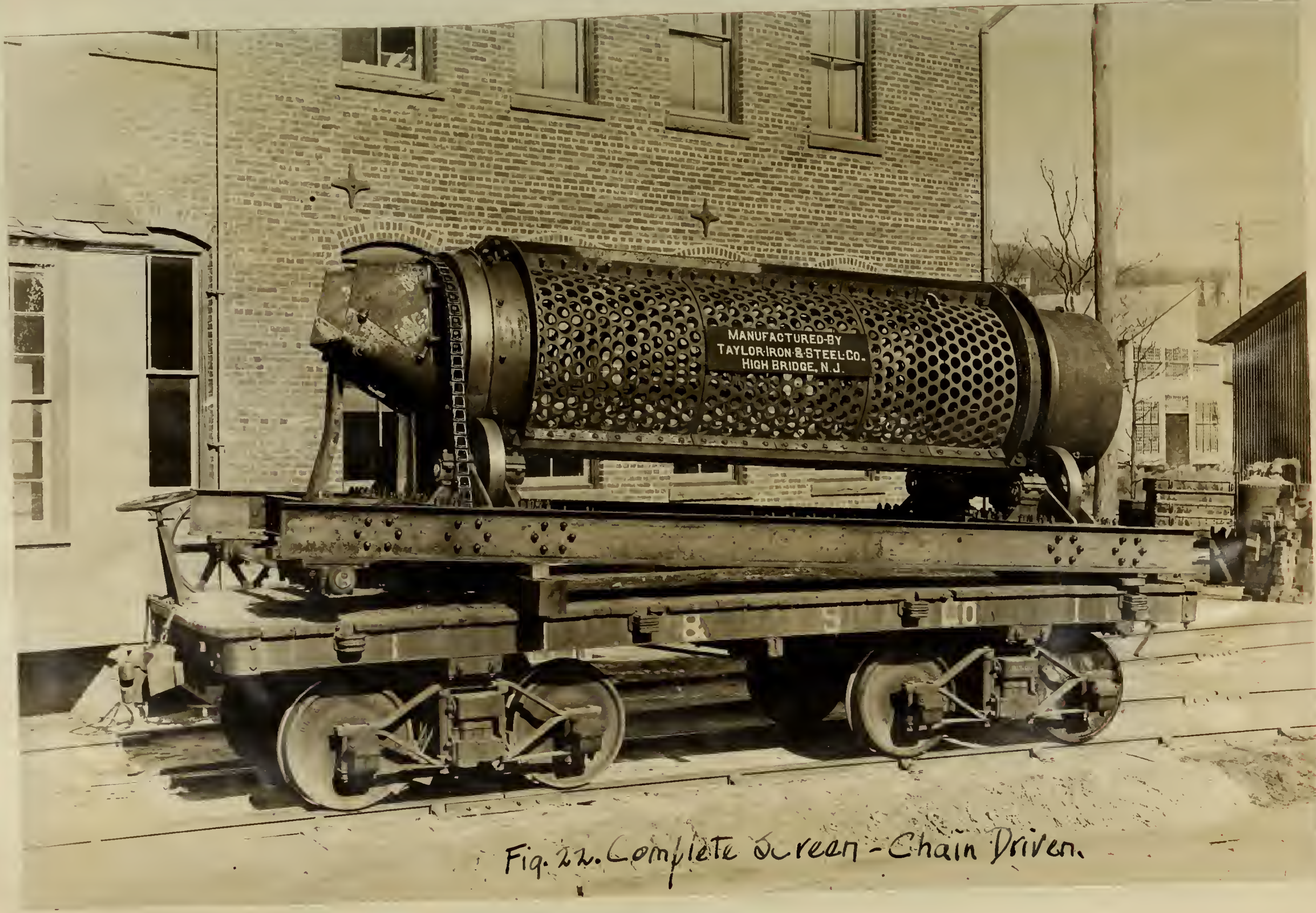

Fig. 22. Complete Screen - Chain Driven.

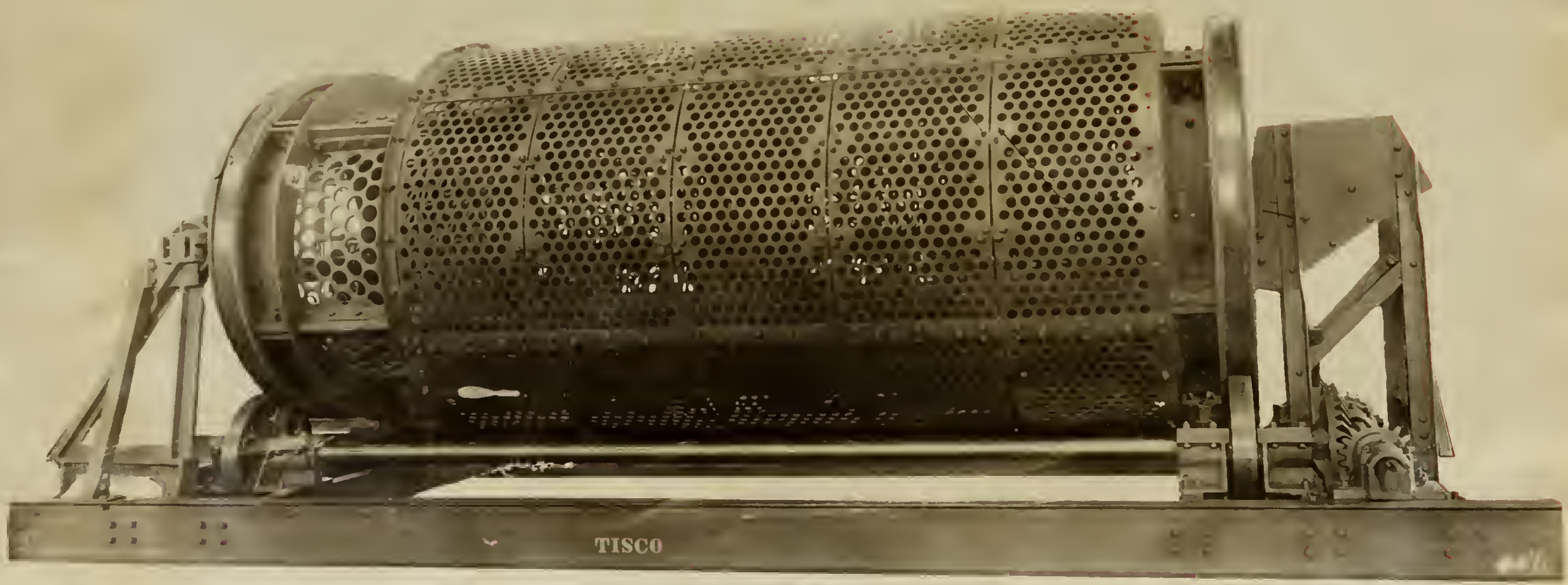

Fig. 23. Complete Screen - Friction Driven.

pulverizing it and to turn out a uniform product. In spite of all precautions a piece of very hard slate, sulphur ore, or perhaps a hammer head will go thru the rolls and manganese steel is the only material which will stand up under such treatment without cracking off the teeth. Shut-downs are very expensive in a large coal breaker and driven tooth rolls in which the teeth are made of hardened steel with a finished shank fitting tightly in drilled holes in the spiders require a great deal of attention and cannot quickly be replaced. Furthermore, the acid water prevalent in most breakers soon corrodes the shank of the driven teeth so they become loose and fall out. Solid roller bodies are used for some of the smaller rolls but usually segments are furnished which are bolted on to the spiders made of cast iron which in turn are keyed to the shafts. Fig. 24 shows a complete roll with 5 segments per circle and staggered teeth designed to break lump coal. Four or six segments to the circle are more common and of course all sizes and spacings of teeth are used to turn out the different sizes. A patented type known as the Lloyd Compound Gear Driven Rolls with special design and arrangement of teeth has recently given very flattering results.

(7) Wheels.

The Anthracite Region has also been a very large user of manganese steel mine car wheels on account of the following properties none of which apply to cast iron wheels, viz: toughness, light-

Fig. 24. Segmental Coal Breaker Roll.

ness, durability, reliability and freedom from breakage. The strength of manganese steel permits a change in the design so that they are usually much lighter than cast iron wheels thus permitting a more rapid handling of cars and reducing the dead load to be hauled. The freedom from breakage is very important. Runaway cars equipped with manganese steel wheels have been smashed into kindling wood, but the wheels have come out of the wreck uninjured. A general Superintendent of one of the large Anthracite Coal Companies whose mines had been completely equipped with manganese steel mine car wheels wrote the writer that "during the cold weather we have had a large number of wrecks caused by cast iron wheels breaking. This has been entirely eliminated by using the manganese steel wheel."

For ordinary tight fits it is customary to furnish ground bores. For a loose fit wheels are designed to permit the use of brass or cast iron bushings which can be renewed when necessary. Fig. 25 shows a large number of manganese steel mine car wheels just after being finished in the Machine Shop and ready for shipment. The treads are merely rough ground approximately flat. The wheels in the left fore-ground have been equipped with an oiling device. Some different designs of mine car wheels are shown by Fig. 26.

The use of manganese steel crane wheels has proven very satisfactory. The sliding action of the flanges against the rails

Fig. 25. Mine Car Wheels.

Fig. 26. Mine Car Wheels.

is very severe in crane wheels causing rolled steel tires to wear out very rapidly while cast iron or ordinary steel wheels will frequently break at this point. The combined toughness and strength of manganese steel crane wheels eliminates both of these complaints. Charging barrow, buggy, and skip wheels for blast furnaces are additional applications. The wheels considered in this paragraph have finished treads as well as bores. Microscopic examination of the tread under load will show a surface contact instead of a line contact as is the case with cast iron or steel wheels which do not have the resilience and spring of manganese steel. This means that loads as high as 90,000 pounds each are today being carried by manganese steel wheels as against 30,000 pounds which is considered the safe working load for cast iron wheels.

(8) Sheaves and Rollers.

For wire ropeways manganese steel sheaves, carrier wheels, idlers, and rollers are in common use. The grooves may be rough ground approximately smooth or may be finish ground depending on how they are to be used. In smaller sizes such castings are solid with a ground bore or in the case of some idlers for use on planes they are made with a shaft or spindle cast integral with the hub which rolls in side bearings. Records of such castings show a life of 30 to 1 as compared with cast iron. Fig. 27 shows a 10 foot manganese

Fig. 27. Sheave Rim.

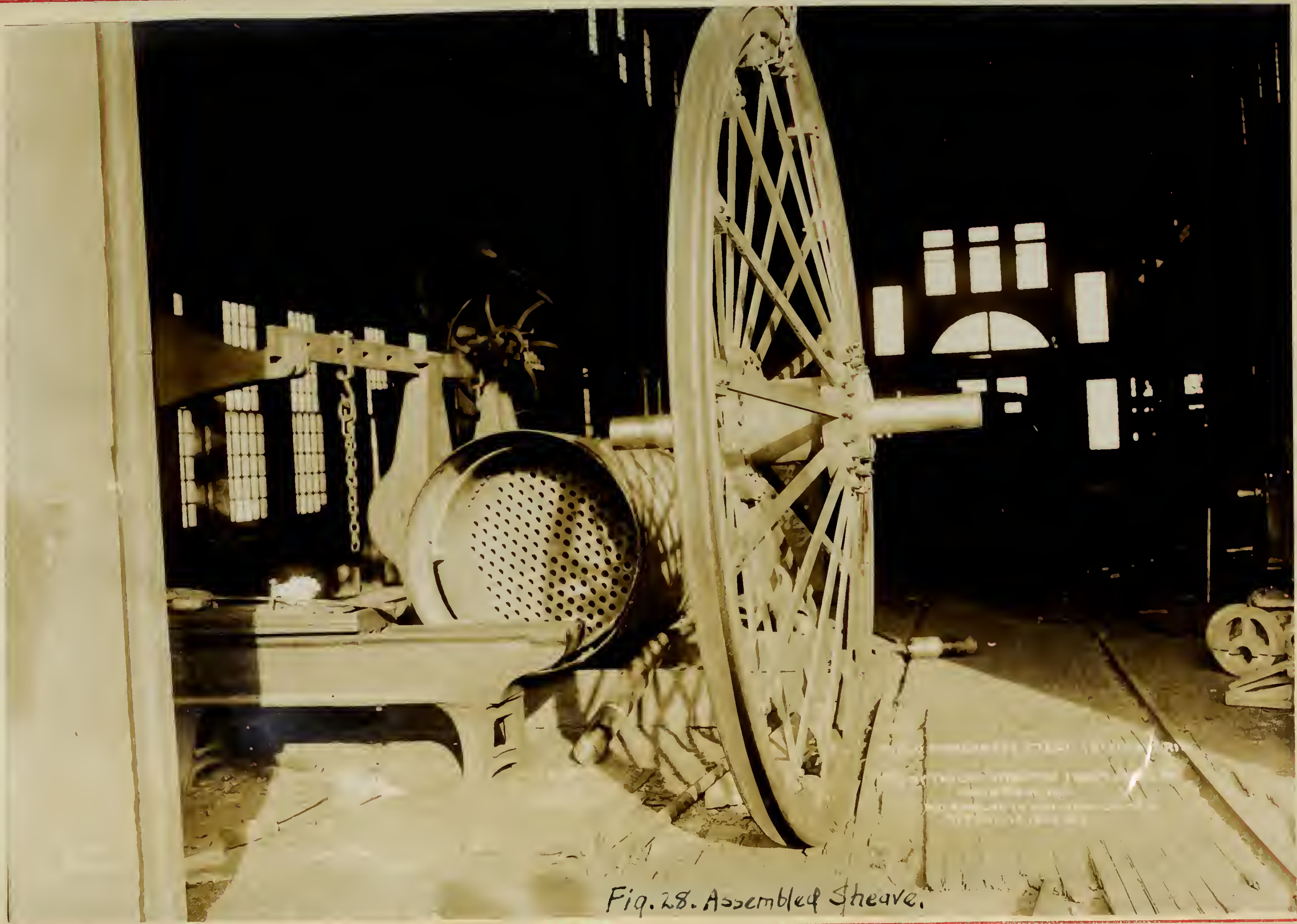

Fig. 28. Assembled Sheave.

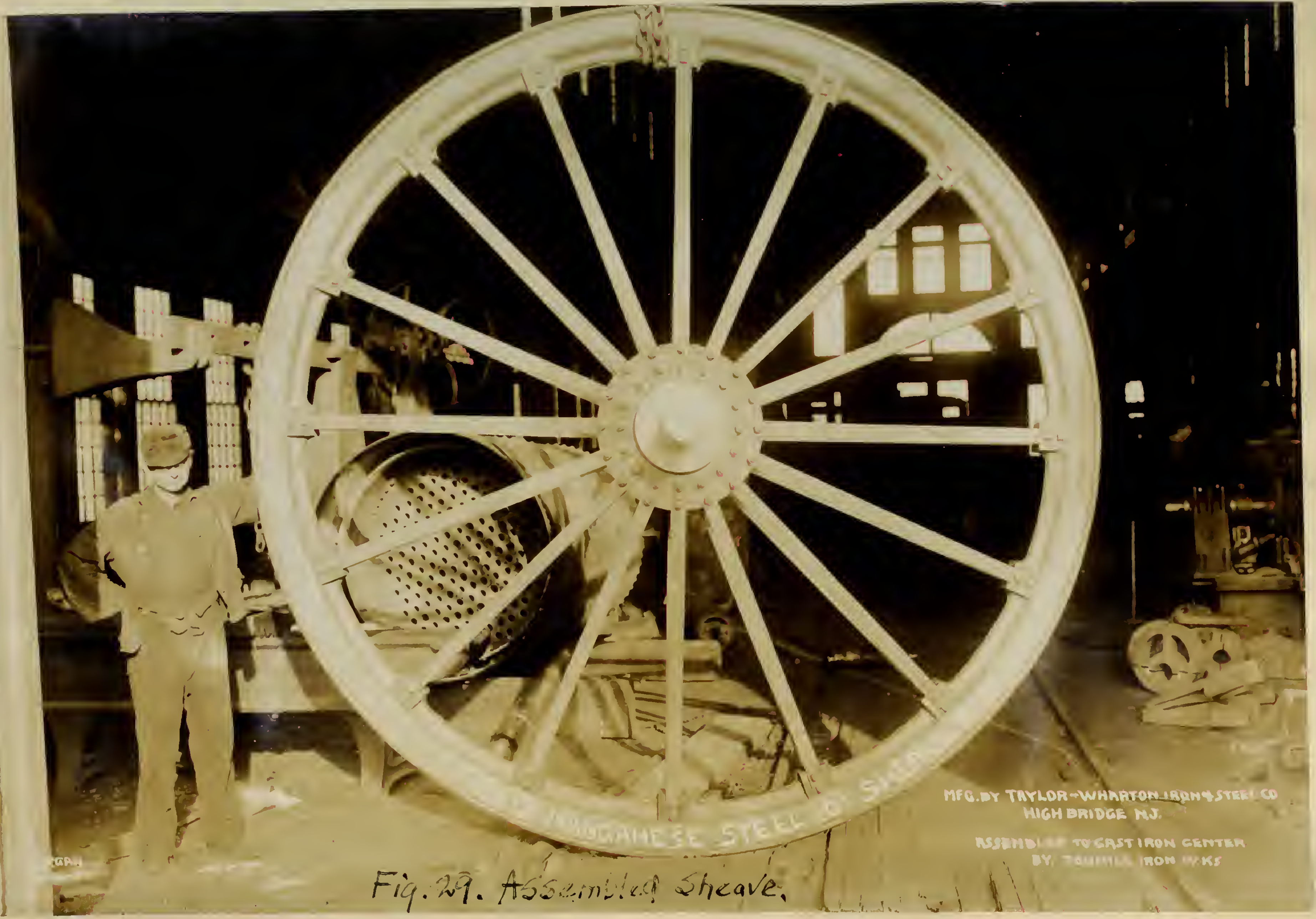

Fig. 29. Assembled Sheave.

steel sheave rim before being assembled. Fig. 28 and Fig. 29 show views of the same casting assembled with wrought iron spokes and cast iron center. This particular casting was installed at the top of a shaft of one of the large Anthracite Coal Mines.

In addition to the increased life of manganese steel sheaves themselves the wear on the groove is so even and gradual that tests show an increased life in the wire rope of from 50% to 100%. Cast iron or hard steel sheaves will wear off in small particles which become lodged in the strands of the wire rope and soon cut it to pieces. Manganese steel does not wear in this way.

(9) Gears and Pinions.

A very common application of manganese steel is for gears and pinions where the loads are heavy and cast teeth are permissible. Some of the best comparative records have been made on such castings especially around cement mills or where dirt and grit get in the teeth. Fig. 30 shows a few such castings and Fig. 31 shows a car load of gears and gear rims which were shipped to a cement company. The larger gear rims are made in sections with the connecting flanges ground true. The bores and usually the faces of the hubs on spur gears are finish ground. The range in sizes of gears is perhaps larger and more varied than in any other manganese steel casting. In some cases gears with ground teeth are used but

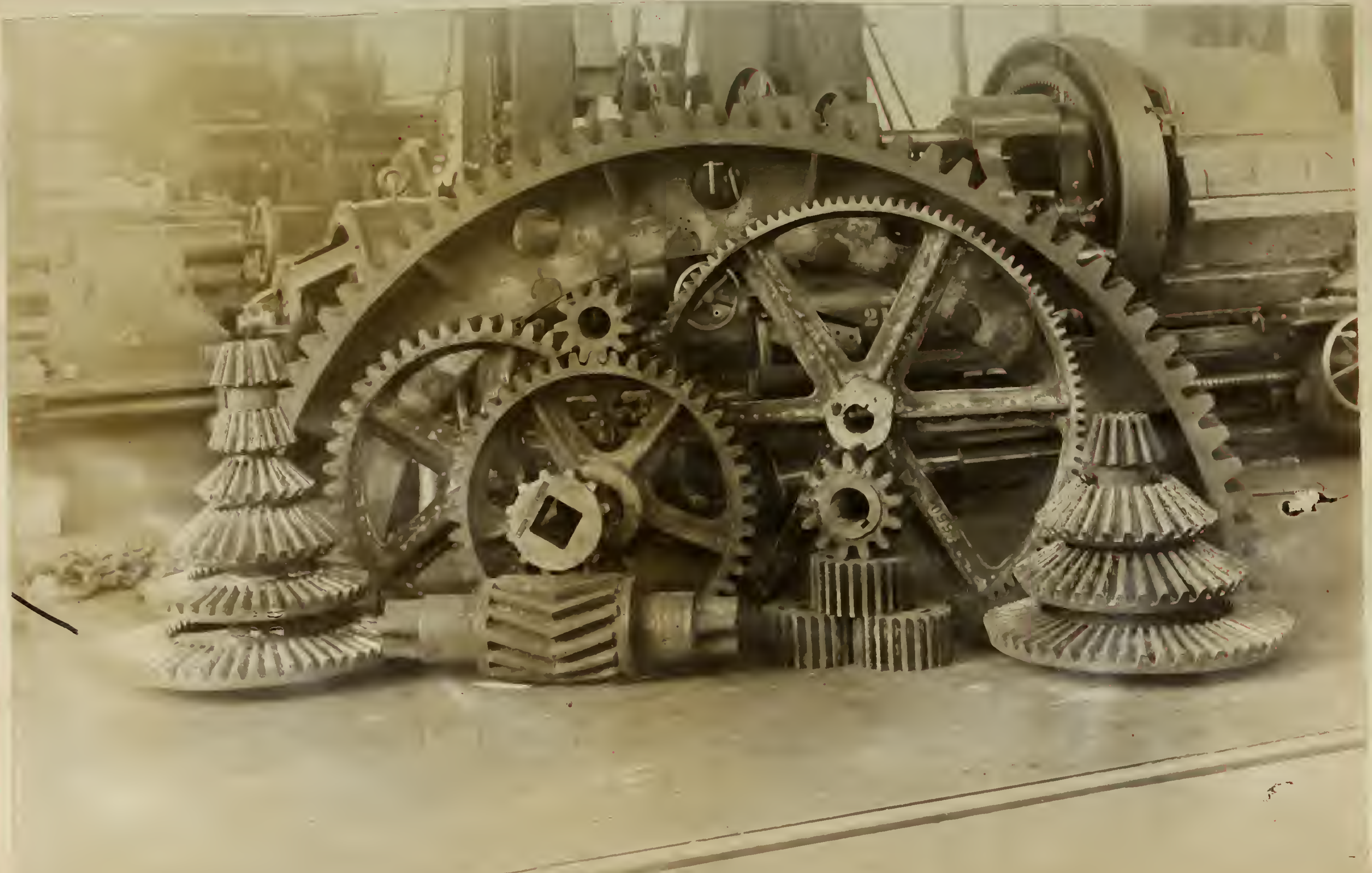

Fig. 30. Gears.

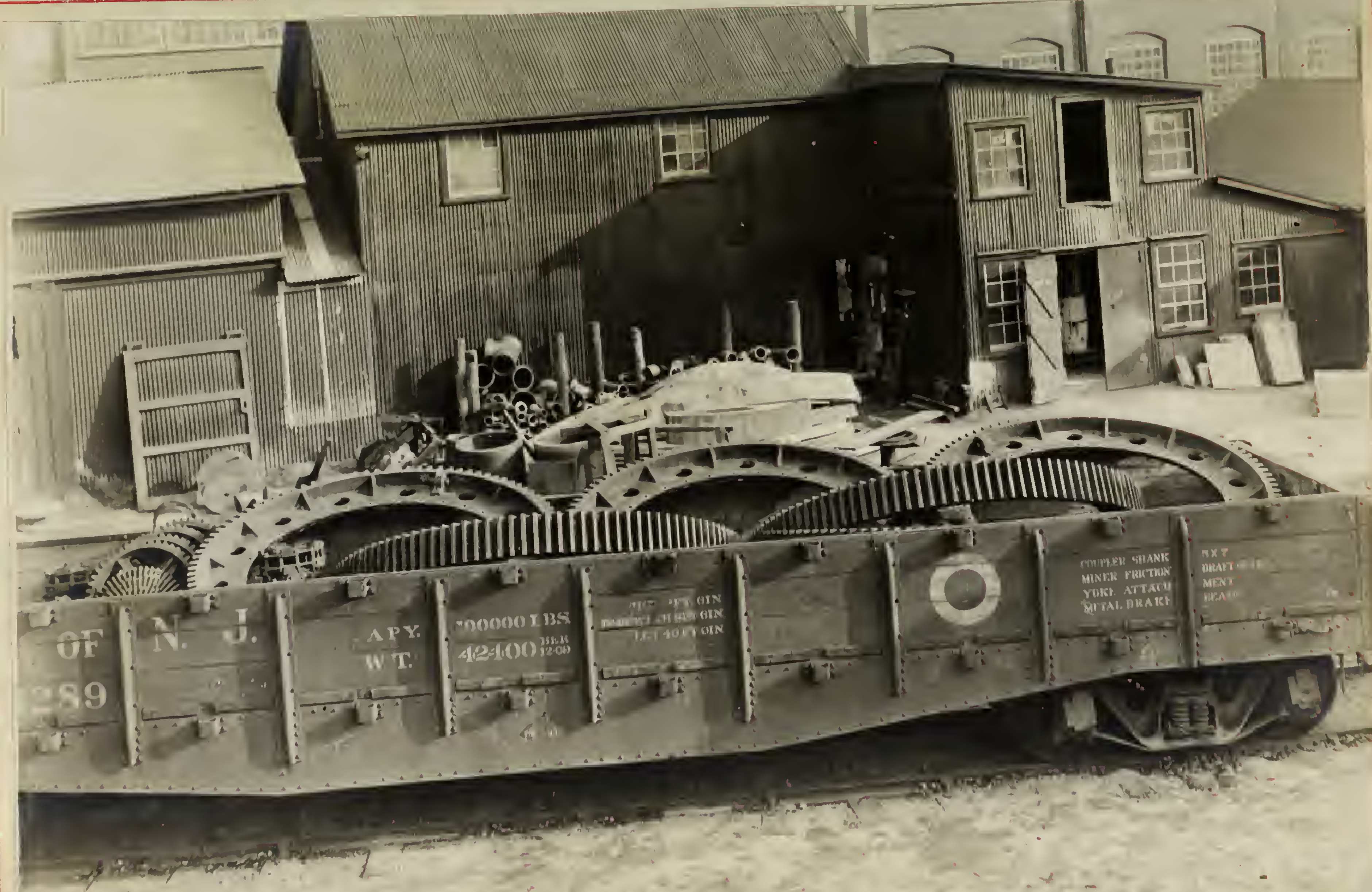

Fig. 31. Gears and Gear Rims.

as yet the application is not very uniform.

(10) Chains and Conveyor Parts.

Manganese Steel Conveyor Chains may be considered an absolute necessity for hard service. They certainly are indispensable around a cement mill and in other places where the failure of a chain link means untold trouble. A few types of chain which are now made very extensively in manganese steel are link belting or detachable, combination including Posselt combination, the "800 series", a developement of the ley-bushed or Peerless chains, the "700 series", or Pintle type, coke machine, "rivetless", draw-bench, pig machine, sand and gravel dredge chain, and many other special designs not mentioned above. Fig. 32 gives cuts of most of the types listed above.

It is not unusual for manganese steel chain to last from seven to twenty times as long as malleable iron chains. Instances of comparative wear between malleable iron and manganese steel chain seems incredible to those who have not made tests for themselves. It is undoubtedly one of the very best applications of manganese steel. Furthermore the safe working strain for manganese steel chain is about 50% greater than for malleable iron.

Chain sprockets are a good application showing about the same relative wear as gears. They are in frequent use with manga-

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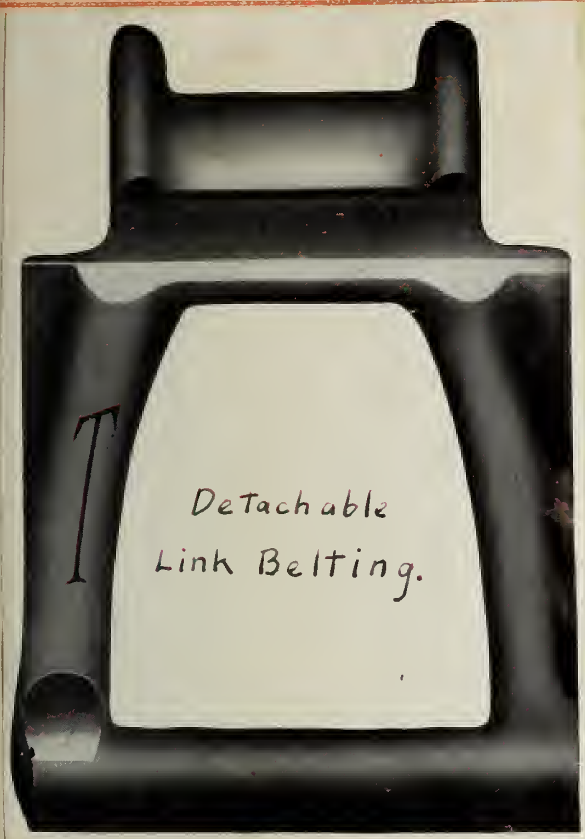
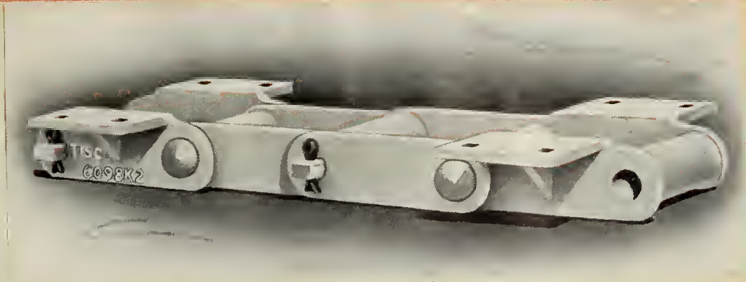
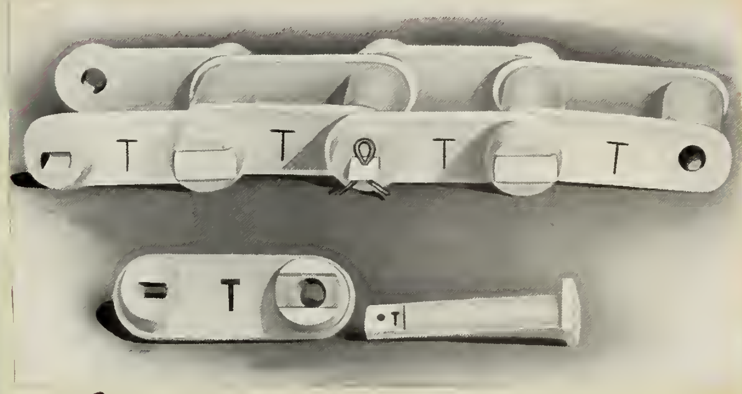


Detachable Link Belting.

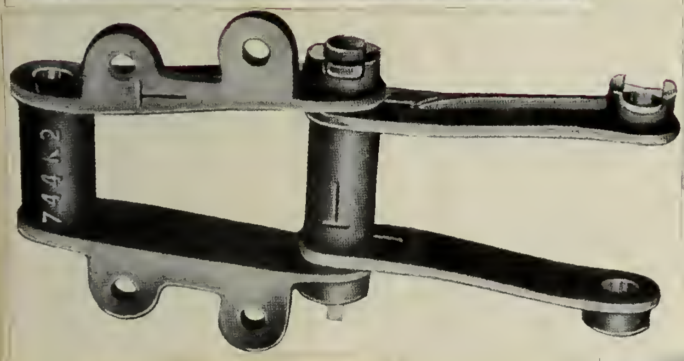


Combination Chain.

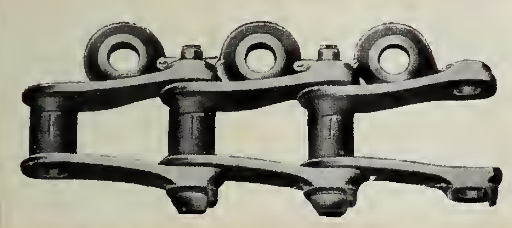


Posselt Combination Chain.

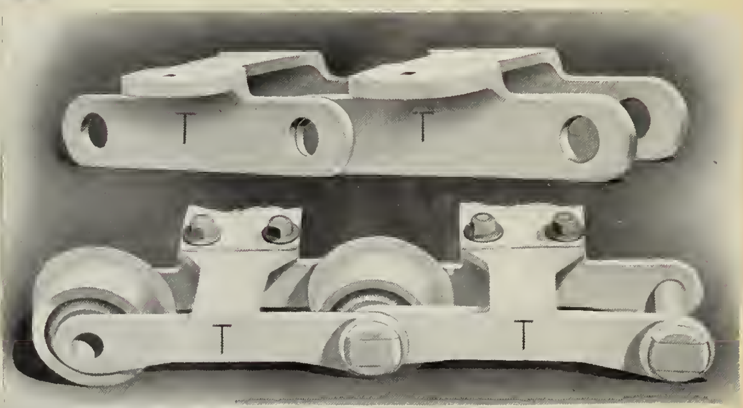
The "800 Series" Chain.



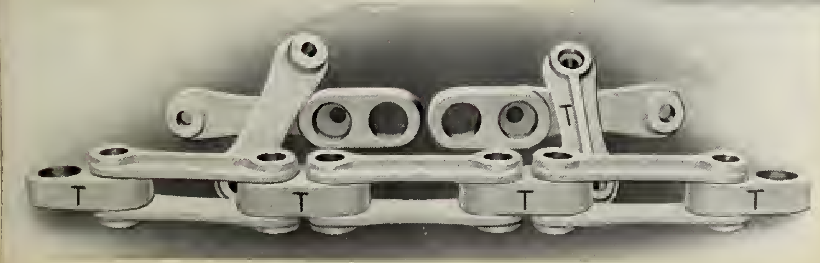
The "700 Series" Chain.



Coke Machine Chain.



Pig Machine Chain.



Draw Bench Chain.

Fig. 32. Chains.

nese chains and while they have never been a very profitable class of work for the founders, still they are used in large quantities. Fig. 33 shows some sprockets together with a few chain links and gears. Manganese steel elevator buckets are used in some instances but the total tonnage of such castings is not large.

(11) Cement Mill Parts.

In addition to the castings all ready described which are used in Cement Mills, a common application which runs into considerable tonnage are the breast and wearing plates, end liners and coarse screens for ball mills and comminuters. Such castings are required to withstand a constant wear and grind and the properties of manganese steel make it particularly suited for such work. Liners for tube mills are also being introduced and Fuller Mill yokes have been used though not with great success.

(12) Iron and Steel Mill Parts.

Wheels, sheaves, gears, and pinions, and chain are used around iron furnaces and rolling mills but such applications have been described for the most part under their respective headings. Blooming Mill pinions are among the very largest castings ever made of manganese steel and although the difficulties of making such castings are enormous, it is claimed that very satisfactory results have been obtained. In addition various rollers, guides, plates,

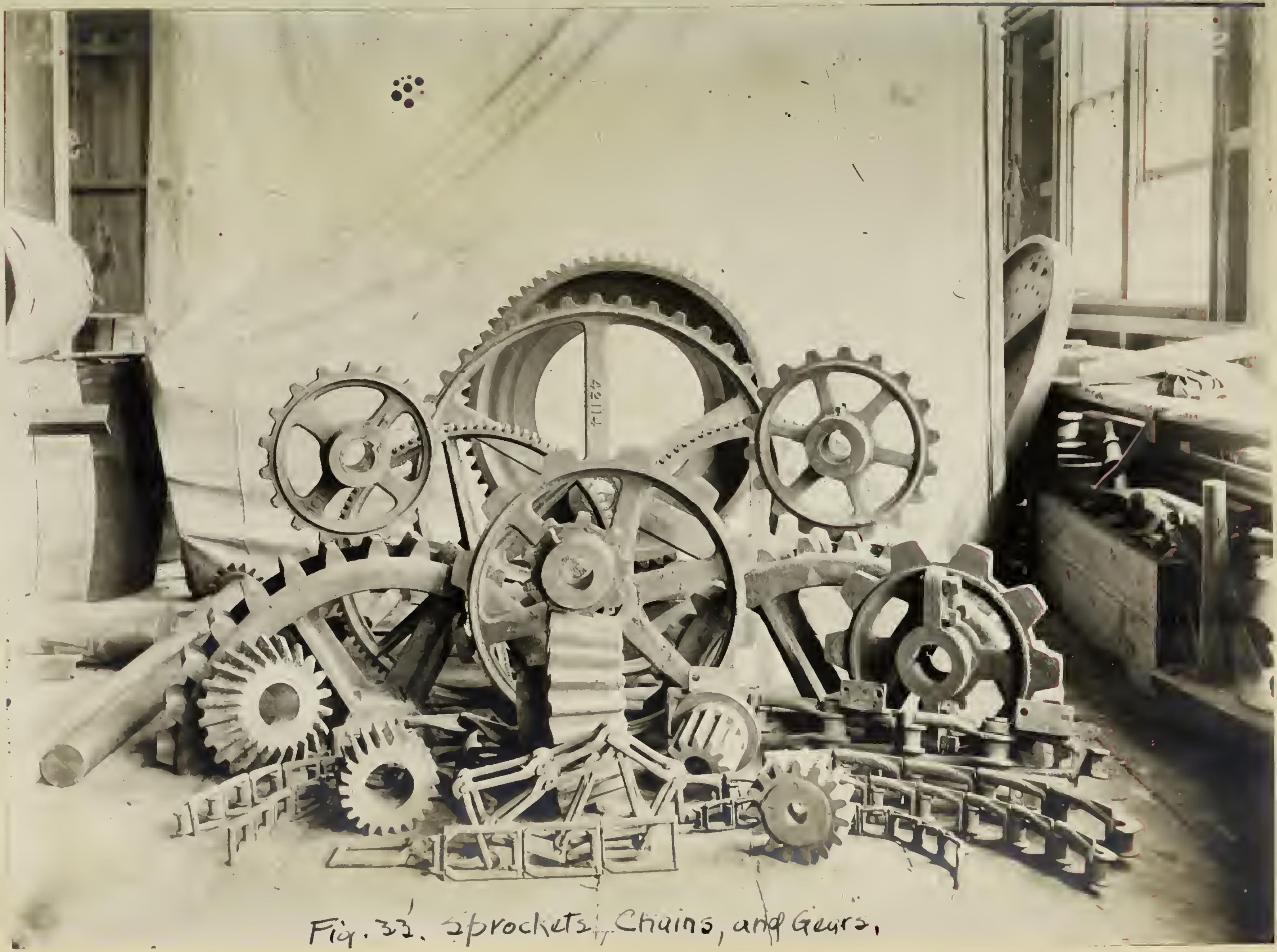


Fig. 33. Sprockets, Chains, and Gears.

spindles, etc., are made in manganese steel when they are subjected to severe strains or wear. The outer covers for lifting magnets are frequently made of manganese steel because it is non-magnetic and tends to concentrate the field downward to the material to be lifted. A very important and fast growing application is for pipe-balls used in a pipe mill. A special heat treatment is given these balls and truly wonderful results have been obtained.

(13) Safes and Vaults.

The fact that manganese steel cannot be drilled and is practically file hard suggested the use of this material for safes and vaults and has opened up a wide field in this connection. The further fact that the temper cannot be drawn by heating is very important in this case and the extreme hardness of the metal thru the entire section and under all conditions renders it truly safe. It is claimed that a manganese steel safe has never been opened with burglarious intent. Fig. 34 shows a large vault door.

(14) Track Work.

The increase of traffic and weight of rolling stock in the last twenty years has opened up one of the largest fields for manganese steel in the way of special track work for both steam and electric roads. Nearly every important crossing has either solid or

Fig. 34. Vault Door.

built up manganese steel frogs, switches, crossings, guard rails, and similar castings. An enormous tonnage goes into the different parts called for in this class of work. As this discussion has not considered rolled manganese steel but as the title indicates has been limited to manganese steel castings the question of rolled manganese steel rails will not be taken up here.

V

Conclusion.

This paper has described in turn the discovery of manganese steel, its peculiar physical properties, the methods employed in the manufacture of castings, and the principal applications of such castings to date. With the information thus obtained the reader is in a position to determine the probability of manganese steel being a success in some particular application not specifically mentioned here. Conversely with a thorough knowledge of what may be expected from manganese steel castings, new applications may be discovered. This is illustrated by the use of manganese steel in the rolled form (rather than castings) for helmets in the present war in Europe as shown by Fig. 35. Sir Robert Hadfield in a letter to the writer dated January 21, 1916 writes as follows:

> "One of the latest uses of our "Era" Manganese Steel of special treatment is for Helmets to protect our men in the trenches and elsewhere, as shown by the accompanying photograph No. 2744, which represents a Helmet which has been attacked with a Webley Self-loading Pistol at a velocity of 580 feet per second and upwards, these bullets being kept out up to quite 1,000 feet per second. Thus shrapnel bullets striking with this velocity cannot perforate the Helmet, and the wearer instead of being killed or wounded is thoroughly protected."

The future of the manganese steel industry appears to be very bright. It is likely that the methods of manufacture will be

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HADFIELD'S "ERA" MANGANESE STEEL HELMETS AFTER SPECIAL TREATMENT.

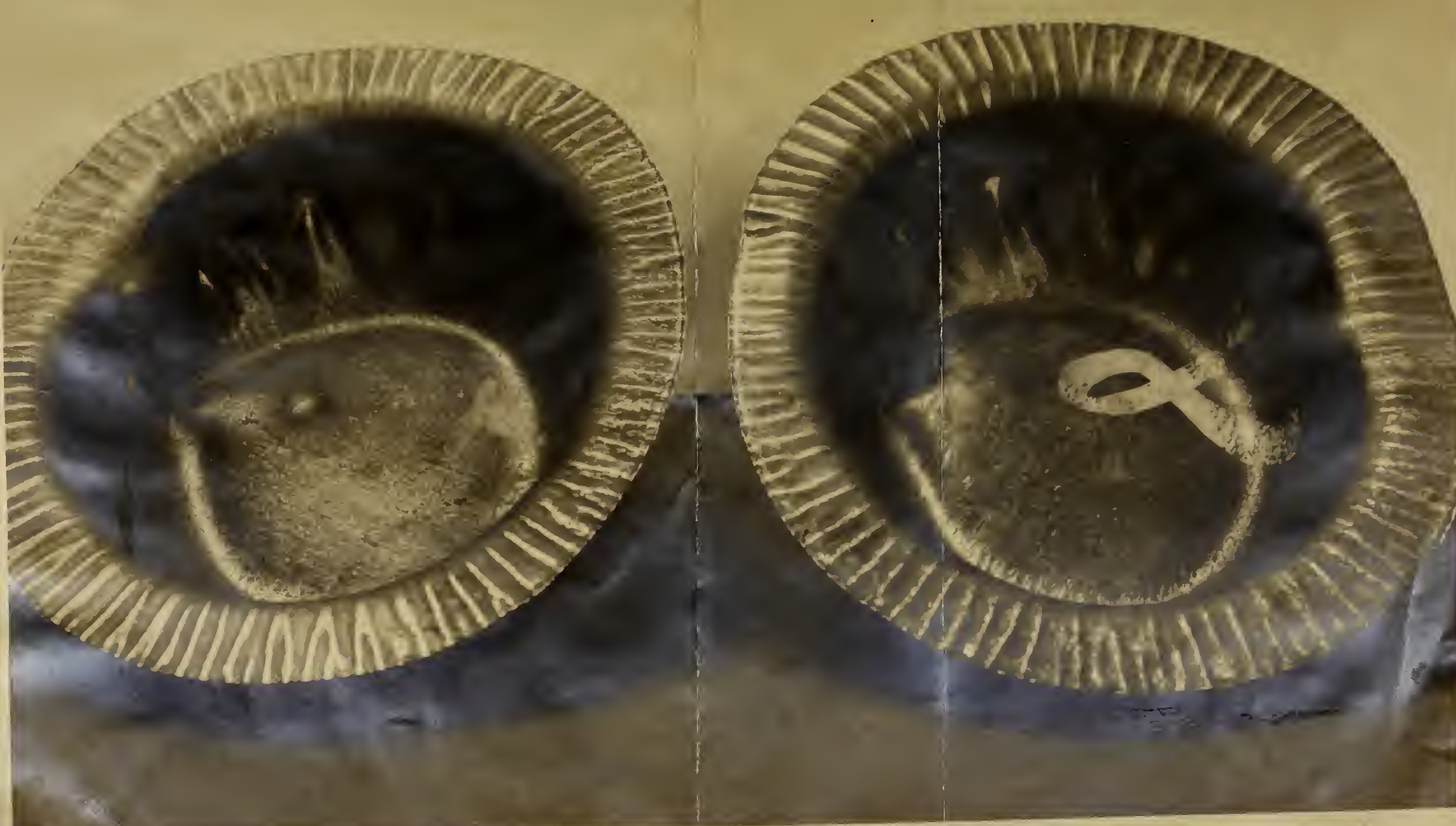

Fig. 35. Helmets

changed quite radically in some particulars. The advent of the electric furnace which will permit manganese steel scrap to be re-melted without the loss of the manganese content gives an idea of what the future may hold forth. Time will tell.

THE END.

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APPENDIX

7/9/82 " " 6 " 23/9/82

Was led to make the following expts. with a view to making a v. hard steel for tramway wheels; they have led to some very curious results perhaps most momentous results that may to some extent quite alter metallurgical opinions as to alloys of iron & steel.

On 7/9/82 cast an ingot with 9 lbs of 80 to 84% Ferro
49 " W.D. 8% Silicon
41 " blown iron
99 – 7.45% Mn.
– 3.96% Si.

Also cast an emery wheel die, two tools, & 2 nail cutters (see further on).

Cast a 7¼ & 4½ nail-cutter (seemed v. hard when grinding off fashes) sent them to Eliza Tinsley for testing. The large cutter weighed 2 oz. less than a cutter of ordinary cutter stuff (melted in pots), much sharper note when hit with hammer. Beautiful clear note. Tried emery wheel but it wd. not grind. V. smooth casting 2" 12" 1¼ settled well plenty of flux. So hard that when chipping off runner it spoilt half a doz chisels & sets. David tried it with a file & seemed to think it was over-harder than chilled metal. Made two tools from a piece of scrap melted in pots. It cut a [illegible] off 6" dia., edge perfect, but broke when trying on next casting. Wd. not hammer, crumbled at any low heat.

This steel evidently extra hard but at expense of toughness so then thought that the excess of silicon was cause of this & left it out. Now comes the strange & peculiar results. Cast two ingots one with

No. 1.
8½ lbs Ferro 80 to 84%
47½ " ordinary casting steel out of ladle
56

=12.% Mn.

30 cwt charge 3 cwt 8% W.D. & 30 lbs Ferro 82% = ·829% silicon = ·437 Mn.

Cast 2 tools & ingot from this. Sent piece of ingot (from bottom end) to Howe see letter in L. B.) & see page further on for results.

= 12.76% Mn
= ·69% Si.
= — C.

No. 2.
5 lbs Ferro as above
53 " ordinary steel as above
58

"go by the pencil Nos."

No. 1 was very tough most peculiar fracture, crystals seemed long & shd. be rather termed fibres. To all appearances it looked v. soft & I thought this is no use so thought Bill [illegible], I said fetch a file when lo & behold it took scratings off file like an emery wheel wd. have done. Notwithstanding this it was exceedingly tough very difficult to top ingot. Dick Smith & David both filed it & pronounced it exceedingly hard. Tried a "nose" tool with it, it cut very well at first but then lost its edge, no chipping mind you. Heated & quenched in water but strange to say if anything softer than before. The result was however not hard for a cast tool, & fancy heat from friction made it lose its temper.

Facsimile of First Notes by Sir Robert Hadfield on Manganese Steel.

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HADFIELD'S PATENT MANGANESE STEEL.

(*From* The Engineer, *February 8th*, 1884.)

In our last impression brief reference was made to some specimens of steel of remarkable properties exhibited at the recent meeting of the Institution of Mechanical Engineers. Some further particulars will be of interest. This manganese steel is really a new steel, and a few years ago could not have been made. It is only through the new manufacture and introduction of higher percentages of ferro-manganese that it can be now made a commercial success. It is sufficiently well known that manganese has been employed for many years in the manufacture of steel in various proportions, but anything exceeding 1 per cent. it has been generally believed would render the metal under treatment worthless, and any further addition thereof in excess of this proportion has been considered impracticable. In fact, Dr. Siemens had stated publicly, on many occasions, that the use of manganese was simply a cloak to cover the impurities in steel making, that it covered a multitude of sins; and this was the general opinion of the steel trade. Messrs. Hadfield, of Sheffield, however, engaged in a long series of experiments and tests, with the object of discovering its truth, and after a considerable expenditure of time and capital, discovered that by adding the ordinary ferro-manganese of commerce to iron or metal, either wholly or to a great extent decarbonised and refined, and treated by any of the ordinary processes, or to steel produced by such processes, in increased proportions sufficient to obtain or produce in the steel or decarbonised iron under treatment a percentage of manganese varying from 7 to 20 per cent., that the most beneficial results could be obtained. Such percentage is regulated according to the purpose for which the steel is required. For instance, to produce a steel suitable for armour-plates and other purposes, as we mentioned last week, they add about 10 per cent. of rich ferro-manganese, containing, say, 80 per cent. of manganese, thus obtaining a steel containing about 10 per cent. of manganese. For railway purposes they add about 11 per cent.; for steel toys and tools, about 12 per cent. They pour this ferro-manganese into the molten steel under treatment, thoroughly incorporating it therewith, and then run it into ingot or other suitable moulds, and allow it to cool, after which it is ready for use, as it requires neither tempering, rolling, forging, nor hardening. This treatment of steel in suitable proportions, according to requirements, appears to be novel, and renders the steel so manufactured harder, stronger, denser, and tougher than most steel now manufactured, even when forged and rolled. This steel may, however, be forged and rolled in the ordinary manner. For casting it has the advantage that it possesses greater freedom from honeycombs and similar defects; but the most peculiar property is its great toughness, combined with extreme hardness. It is through this that the hitherto indispensable processes of rolling, forging, hammering, hardening, and tempering may be dispensed with, thus effecting for many articles an enormous economy in time, labour, and expense. In casting its fluidity enables fine steel castings to be made without misrunning, and approaching in smoothness iron castings. As far as has been yet observed, it does not, when cast, settle so much, nor does it draw, like ordinary steel castings, at the junction of the thick and thin parts. It would thus appear that steel so manufactured is specially adapted for making steel rolls to replace those of chilled metal, iron, armour plates, the larger edge tools, and articles known in the steel trade as steel toys. Its value for agricultural wearing parts will be at once seen, as these may be cast therefrom without requiring either forging or tempering, for like large edge tools, they will be ready for use after grinding.

It appears that this use of manganese renders the use of silicon to obtain soundness unnecessary. Amongst the samples of the steel placed on the table at the meeting of the Mechanical Engineers were a sample test bar containing 12 per cent. manganese, bent double when cold, though hard enough for turning iron; a sample from same ingot, shows a tensile strength of 42 tons per square inch, with 20·85 per cent. elongation; several hammered pieces; a manganese adze, containing 20 per cent. manganese, just as it left the mould; an axe, containing 12 per cent. manganese, just as cast in the rough, had chopped through ½in. square iron. This, like the others, had not been hardened or tempered, only the edge ground. There was also a large size, about 1¼in., wood chisel, which had been used in the pattern shop fifteen months. This was of steel, containing 14 per cent. manganese; a corve wheel, which had been tested with sixty heavy blows, and showed a peculiar crystallisation. It contained 12 per cent. manganese. None of this steel has the slightest magnetic capacity; it is a very poor conductor of electricity—worse than iron wire—yet fine drillings or scrapings from it are attracted by the magnet. We are informed that it does not seem to oxidise easily, though tested by Messrs. Hadfield in sea water. It is said not to corrode as much as ordinary steel—which is exactly what would not be expected from the many statements to the effect that manganese made steel easily corrodible. It is said not to tarnish easily, and it is found that heating it to a white heat and quenching in cold water instead of hardening it, causes it to become softer and tougher. The tested sample mentioned above was heated to a white heat and allowed to cool down on the shop floor.

It is rather curious that the properties herein found should only be now found, and after finding a steel that is at the same time very hard, very tough, not attracted by the magnet, and with considerable elongation, we may next expect anything to turn up to upset one's ideas as to the characteristics of steely materials.

LIST OF PAPERS BY
SIR ROBERT HADFIELD, F.R.S.
ON "MANGANESE STEEL"

No	TITLE	NAME OF INSTITUTE OR PRESS REFERENCE	YEAR
1.	"Manganese Steel"	"Engineer"	1884
2.	"Manganese Steel"	Institution of Civil Engineers	1888
3.	"Some Newly-Discovered Properties of Iron and Manganese"	Institution of Civil Engineers	1888
4.	"On Manganese Steel"	Iron and Steel Institute	1888
5*	"Hadfield's Patent Manganese Steel"	Amer.Inst. of Mining Engineers	1884
6*	"Tests of Manganese Steel"	Amer.Inst. of Mining Engineers	1886
7†	"Manganese Steel"	Amer. Soc. of Mech. Engineers	1891
8†	"Manganese Steel"	Franklin Institute	1893
9	"Iron Alloys, with special reference to Manganese Steel"	Amer.Inst. of Mining Engineers	1893
0	"The Results of Heat Treatment on Manganese Steel and their Bearing upon Carbon Steel"	Iron and Steel Institute	1894
1	"Alloys of Iron, Manganese, and Nickel"	Institution of Civil Engineers	1903
2	"Iron and Steel Alloys"	"Iron and Steel Metallurgist and Metallographist"	1904
3	Presidential Address	Iron and Steel Institute	1905
4	Seventh Report of the Alloys Research Committee "On the Properties of a Series of Iron-Nickel-Manganese-Carbon Alloys"	Inst. of Mechanical Engineers	1905
.5	"Heating and Cooling Curves of Manganese Steel"	Iron and Steel Institute	1913
.6	"Research with regard to the Non-Magnetic and Magnetic Conditions of Manganese Steel"	Amer.Inst. of Mining Engineers	1914
.7	"Manganese Steel Rails"	Amer.Inst. of Mining Engineers	1914
.8	Contribution to Discussion on Mr W.S.Potter's paper on "Manganese Steel"	Amer.Inst. of Mining Engineers	1914
.9	"The Magnetic and Mechanical Properties of Manganese Steel"	Iron and Steel Institute	1914

* By J.D. Weeks. † By H.M. Howe.

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AWARDS AND HONOURS
to
SIR ROBERT HADFIELD, F.R.S.

Telford Gold Medal and Premium	Institute of Civil Engineers	1888
Two Gold Medals	French Société d'Encouragement pour l'Industrie Naticnale	1890 1900
John Scott Medal and Premium	Franklin Institute of America	1891
George Stephenson Gold Medal and Premium	Institute of Civil Engineers	1899
Howard Quinquennial Prize and Premium	Institute of Civil Engineers	1902
Bessemer Gold Medal	Iron and Steel Institute	1904
"James Forrest" Lecturer and Premium	Institute of Civil Engineers	1906
Honorary Member of American Institute of Mining Engineers	Elected by the American Institute of Mining Engineers	1906
Fellow of the Royal Society	Elected by the Royal Society	1909
Special Gold Medal	French Société d'Encouragement pour l'Industrie Nationale	1910
Elliott-Cresson Gold Medal	Franklin Institute of America Awarded at the same time as the Gold Medal to Rutherford.	1910
Electrical Institute Premium	Instn. of Electrical Engineers	1911
Honorary Degree of Doctor of Metallurgy (D.Met).	Conferred by the Sheffield University	1911
Honorary Foreign Member of the Royal Swedish Academy of Science, Stockholm.**	Elected by the Royal Swedish Academy of Science	1912
Honorary Member of the American Iron and Steel Institute	Elected by the American Iron and Steel Institute	1912
Honorary Degree of Doctor of Science (D.Sc).	Conferred by the Leeds University	1912
Member of Munitions Inventions Panel	Elected by the Ministry of Munitions.	1915

* All these Awards were made to Sir Robert Hadfield for his invention of Manganese Steel.

** The only other British Honorary Foreign Members of the Royal Academy of Science, Sweden, are Darwen; Gill; Rayleigh; Thompson; Rutherford; Ramsey; Marshall; Thompson (Silvanus); Marconi.

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REMARKS BY VARIOUS SCIENTISTS ON THE RESEARCH WORK OF SIR ROBERT HADFIELD, F.R.S., in connection with MANGANESE STEEL.

GREAT BRITAIN

DR J.E. STEAD, F.R.S. (of Middlesbrough)

Bessemer Gold Medallist, and one of the present leaders of metallurgical thought.

"Hadfield had surprised the whole metallurgical world with the results obtained. The material produced was one of the most marvellous ever brought before the public".

SIR W.C. ROBERTS-AUSTEN, F.R.S. (the late)

former President of the Iron and Steel Institute, and one of the leaders of his day in this branch of science.

"Hadfield had introduced a most remarkable series of materials and was entitled to the gratitude of all metallurgists and engineers".

PROFESSOR H. APPLETON, M.A.

Public Orator at the University of Sheffield, on the occasion of the conferment upon Sir Robert Hadfield of Honorary Degree of Doctor of Metallurgy.

"Hadfield's discovery of Manganese Steel not only revolutionised the whole trend of metallurgical thought, but proved to be of extraordinary and world-wide utility. By the extent and variety of his research work in other directions he has added enormously to the scientific knowledge of iron and steel and their alloys. As an investigator his work has received universal recognition".

PROFESSOR J. GOODMAN, M.Inst.C.E.,

Public Orator at the University of Leeds, on the occasion of the conferment upon Sir Robert Hadfield of Honorary Degree of Doctor of Science.

"By his far-reaching discovery of Manganese Steel, Hadfield has revolutionised certain branches of engineering. By his investigations he has thrown much light on the influence of low temperatures upon steel and also on segregation in steel ingots. He has also taken an active interest in the development of scientific and technological education".

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FRANCE

MONSIEUR F. OSMOND (the late),
Bessemer Gold Medallist, and the leading metallurgist in France of the last twenty years.

"The Hadfield discovery and invention of Manganese Steel was not only the discovery of a new alloy, curious, of great scientific value, and yet useful, but in the history of the metallurgy of iron it ranked as a discovery, equal in importance to that of the effect of quenching Carbon steel, and was the only one of the same order which it had been reserved for our age to make".

MONSIEUR A. POURCEL (Paris),
Bessemer Gold Medallist, the well known French metallurgist,

"Considered the production of Manganese Steel the most important event in practical metallurgy during the last ten years, and which might take its place beside the result of the labours of Gilchrist, Bessemer, Siemens, Martin, and Mushet".

GERMANY

Mr G. MARS (Dusseldorf),
the eminent German writer on Metallurgy, in his recent book "Die Spezialstahle"

"The most extensive experimental researches, which may be said to have laid the foundation for entire knowledge of steel alloys, were carried out by Hadfield in the eighties of the last century".

"His two works on Manganese Steels and Silicon Steels have become of decisive importance as regards the development of the technics of steel alloys. They not only supplied a wealth of important facts from the purely scientific point of view, but they subsequently led up to the evolution of many new qualities of steel".

"The exceedingly thorough investigation of manganese steel has been carried out by Hadfield in a manner which must be held exemplary for all times".

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AMERICA

PROFESSOR BRADLEY STOUGHTON (New York)

the well-known American Metallurgist in his work "The Metallurgy of Iron and Steel", says

"We owe the discovery of Manganese Steel to the untiring ingenuity of Hadfield, and its story will be an inspiration to every inventor. It resulted in a material whose combination of great hardness and great durability was hitherto unknown and might readily have been believed to be impossible. Constant study and perseverance must have been the qualities that led to this revolutionary invention".

PROFESSOR H.M. HOWE,

the eminent American Metallurgist, in his work "Iron, Steel and other Alloys", says

"It has a combination of properties which, so far as I know, was not possessed by any other known substance when this remarkable alloy, known as Manganese Steel, was discovered by Hadfield. His further and extremely important papers on Manganese Steel have very greatly increased our knowledge of this remarkable substance".